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U. S. A R M Y
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

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AS AD NO.

TRECOM TECHNICAL REPORT 63-37

**OPERATIONAL ANALYSIS OF THE USE OF
CUSHION VEHICLES IN SUPPORT OF THE ARMY'S
OFF-ROAD LOGISTIC MISSION**

Task 1D021701A04807
(Formerly Task 9R99-01-005-07)
Contract DA 44-177-TC-855.

August 1963

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prepared by:

BOOZ-ALLEN APPLIED RESEARCH, INC.
Bethesda 14, Maryland



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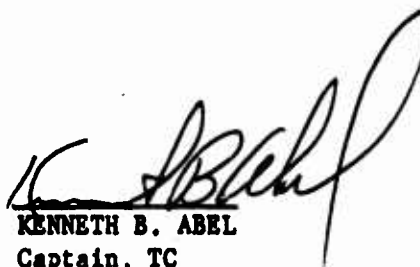
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FORT EUSTIS, VIRGINIA

Consideration of the use of air-cushion vehicles over land presented a variety of types and sizes each posing problems peculiar to its configuration. So that the supporting research program could be more productive, an operational analysis was undertaken to determine what size, range, payload, performance, and power-plant combination would be most feasible for development in the 1965-1970 time frame. Proper emphasis could then be placed on problem areas which would delay development.

The off-road spectrum investigated ranged from high-performance air-cushion vehicles to wheeled vehicles which employed air-cushion assist where soft soils or water would tend to immobilize the vehicle.

For lack of a more definitive yardstick, the system cost effectiveness was expressed in dollars per ton-mile although it is recognized that the use of critical materials, susceptibility to dispersion, vulnerability, and response time would have a significant bearing in determining the optimum configuration.

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Task 1D021701A04807
(Formerly Task 9R99-01-005-07)
Contract DA 44-177-TC-855
August 1963

**OPERATIONAL ANALYSIS OF THE USE OF
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TRECOM Technical Report 63-37

Prepared by
Booz-Allen Applied Research, Inc.
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for
U.S. ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

PREFACE

The study presented in this report was undertaken by the Aeronautical and Transportation Research group of the Research and Analysis Division -- Booz-Allen Applied Research, Inc., 4815 Rugby Avenue, Bethesda 14, Maryland, and sponsored by the U. S. Army Transportation Research Command under Contract DA 44-177-TC-855. This research program was carried out under the supervision of Mr. Peter Fielding. The study began in July 1962 and was completed in February 1963. Mr. William E. Sickles of the U. S. Army Transportation Research Command was the Project Officer.

The contract directed the contractor, among other things, to determine the feasibility of air cushion vehicles with and without wheels to operate off-road with the maximum efficiency and the minimum of penalties for highway operation. It directs particular attention to a standardized environment and the comparison of current off-road vehicles to perform in this environment. As a separate task, the contractor was also asked to define an air cushion trailer having optimum performance.

The authors are indebted to the personnel of the GEM Group at USATRECOM for their guidance and cooperation and also to all the members of the GEM monitoring board in setting up the standardized environment mission.

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SUMMARY

This report is the result of a seven-month operations research study covering the role of the air cushion vehicle (ACV) in the Army's off-road logistic mission, and the definition of an optimum air cushion trailer (ACT).

The study is based on a standardized "off-road" environment broken down into nine segments covering normal highway surfaces through to overwater operation. These segments have been quantitatively and qualitatively described with each representing a percentage of the off-road mission range. This range has been varied between 25 and 250 statute miles in order to obtain a comparison of the degrees of mobility and cost effectiveness of both pure and wheeled air cushion vehicles with conventional off-road equipments.

An analytical technique to determine the required horsepower for wheeled ACV's in each environment is developed, and a mathematical deterministic model covering the performance of each vehicle is programmed for a CDC 60 computer.

A cost methodology is proposed for air cushion vehicles and used to compare their operating costs with conventional off-road vehicles and the "Chinook" helicopter.

Optimization techniques using state-of-the-art data are also developed for the determination of a range of air cushion trailers leading to the definition of a trailer with minimum operating costs.

Conclusions and recommendations based on the results of the study are provided for both the pure air cushion vehicle and the air cushion vehicle with wheels and the air cushion trailer.

INTRODUCTION

The introduction of the air-supported vehicle in the early 18th century by Emanuel Swedenborg was not seriously considered until John B. Ward obtained his U. S. patent for a partially wheel-supported machine in 1876. Since that date, there have been numerous attempts to utilize the air cushion principle in a similar way to provide off-road mobility. However, until modern technology produced means to provide the fluid dynamic understanding, lightweight structures, and power plants, these attempts were relatively academic. In a similar way, the wheel and its many variants have also been dependent on modern technology. Vehicles in general have been limited to operating on relatively hard or firm surfaces until recent times, when large strides have been made with specially constructed tires which result in extremely low ground pressures.

Today, there appears to be a large potential for combining the best features of both ideas for increasing mobility. For highway operation, the air cushion vehicle, mixing with other vehicular traffic on normal roadways, is practically an impossibility due to the lack of control necessary to avoid collision. Similarly, the good roadway performance of the wheeled vehicle must be offset against its relatively poor performance over the softer terrains off the road.

Within the last two to three years, the Hawker Siddeley, Vickers and Westland groups have produced vehicles combining the air cushion principle with wheels. At the time of publication, the Vickers-Armstrong Hovercraft Division has successfully demonstrated a production Land-rover vehicle fitted with a simple air cushion kit. The promise of the dual support system is the basis for this study, inasmuch as both "on-road" and "off-road" performance are considered mandatory for the Army's logistic support mission.

The purpose of the study is to evaluate the performance of "pure" air cushion vehicles and wheeled ACV's, using a standard environment, and to compare the results with the performance of Army off-road logistic vehicles which are in existence or may be anticipated in the 1965-1970 time frame. As a secondary objective, an optimum air cushion trailer, capable of being towed by a number of vehicles, is defined.

In any operations research oriented study, particularly those concerned with the relative cost/effectiveness of new and undeveloped vehicle systems, it is necessary to form a number of assumptions. These assumptions must be based on present state-of-the-art data and the experience of all concerned in the development of the new concept. In many cases, these data are, at best, educated guesses; it is therefore necessary that they be treated with a high degree of conservatism if complete objectivity is to be realized in comparing the new concept with well established vehicle systems. Accordingly, it should be realized that if high costs are associated with a performance not supplied by any other vehicle, these costs should be balanced against this advantage. It shall also be understood that as the state of the art develops, substantial gains may be made in achieving this performance with respect to lower initial and operating costs. With these factors in mind, the study was started in July 1962.

A standard environment and mission was first outlined and approved by the Operations Research Project Monitoring Group (GEM) at a meeting held on August 3, 1962, at the Office of the Chief of Transportation, U. S. Army Transportation Corp, Washington 25, D. C. Further inputs to the study were made by the U. S. Army Transportation Combat Development Agency, Fort Eustis, Virginia, on October 4, 1962. These inputs have governed to a large degree the areas of logistic and combat support doctrine and the determination of payload parameters.

By combining these inputs into a "off-road" model concerned with the performance characteristics of both "pure" ACV's and wheeled ACV's it has been possible to evaluate the cost/effectiveness of each vehicle and to compare the results with other off-road concepts. In the evaluation of wheeled ACV's, it was first necessary to establish analytical procedures for the power required to operate in the standard environment. As no data were found to be available on off-loading wheels for operating in certain terrains, these procedures were explored in detail, together with the parameters necessary for inclusion of wheel data in the model. In a similar way, a methodology for arriving at first and production costs of air cushion vehicles was established. The result was a cost/effectiveness comparison of various types of ACV's with currently available logistic carriers, which included costs of engineering support as well as the initial and operating cost of the equipment.

Finally, the report presents four separate techniques for evaluating and optimizing air cushion trailers to be drawn by a variety of off-road vehicles and the relative cost/effectiveness of these vehicles.

In summary and in keeping with the contractual work statement, this study covers:

- . Definition of an optimum air cushion vehicle configuration, in terms of cost/effectiveness, for the Army off-road logistic mission.
- . Evaluation of the vehicle in terms of impact on the Army's logistic system.
- . Estimation of equipments, engineer and maintenance support, and manpower loadings.
- . Comparison of the cost/effectiveness of an optimum ACV with other Army off-road vehicles and the Chinook helicopter.
- . Evaluation of an optimum air cushion trailer.

Recommendations and conclusions based on the results of these investigations completed all aspects of the statement of work for Contract DA 44-177-TC-855.

CHAPTER I

ASSUMED MISSION AND OPERATING ENVIRONMENT

1.1 DOCTRINE

Through the years, improvement of tactical and logistic mobility has been a continuing goal of the combat and technical services of the United States Army. In this era of battlefield nuclear weapons, advanced firepower, and improved communications and command capability, the requirement for mobility is no less important than at any previous time.

The general doctrine of logistic mobility in support of combat operations in present and future warfare has been spelled out in studies conducted by the Transportation Combat Development Agency (formerly Transportation Combat Developments Group). Under this doctrine, general reliance for logistic support of combat operations in the immediate future will be on motor transportation, with rail and water transportation being used when available and when needed. Air transportation will move from the premium transportation category into a role more competitive with motor transport, particularly in the field army area.

Motor transport operation is divided into line-haul traffic and local area traffic. Requirements for off-road mobility increase as the distance to the front line decreases. The highest degree of mobility will usually, but not always, be required in the combat group area of the division zone. Off-road mobility will be required to a lesser extent in the field army zone and the communications zone. The increased mobility requirements in the forward zone are due to wider dispersal of units from usable roads and less engineer and maintenance support.

Desirable characteristics for logistic transport of any kind include dependability, reliability, capacity, and economy. The mobility system and its components must be dependable throughout the entire period of required operation. This means all-weather operation and a high degree of strength and durability. The system must also be reliable; that is, there must be no unknowns in operational or maintenance capabilities and no significantly weak links in equipment

or personnel. The system must have the capability to meet the logistic requirements of the operation. These include speed, payload, and range. The largest possible ratios of payload to curb weight are also important for logistic vehicles. Finally, the system must be economical with respect to fuel, operating manpower, and maintenance. If possible, first cost of equipment should also be low.

The Combat Development Agency has adopted a concept of "concurrent mobility" for logistic vehicles. In this concept, the mobility of the logistic support unit in the forward zone is equal to that of the tactical vehicles used by combat forces, without employment of engineer support. In addition, mobility in line-haul operations must be sufficient to provide all-weather capabilities with limited engineer support. Prepared routes which offer higher speed and increased payload will be used whenever they are available, if not denied by enemy action. Because of changing concepts of strategy and tactics as well as new weapons development, it will no longer be possible to rely entirely on road networks and other prepared routes. Therefore, some percentage of logistic support vehicles must be capable of off-road operation in any area in which military action may occur.

Economy of operation is an important parameter for all logistic vehicles used in the communications zone. Because of the continuous high-capacity operations in this area, cost of vehicles, fuel, and manpower must be reduced to the lowest possible ratio to the tonnage of supplies delivered. Under concepts of "dispersion in depth", now being adopted, greater LOC (line of communication) distances emphasize the importance of economical operation for line-haul missions.

The air cushion concept has been considered for application to off-road mobility systems ever since the early days of its development history. The basic characteristics of the air cushion vehicle, a member of the Ground Effect Machine family (GEM), provide a strong incentive for consideration of this application. The ACV is basically a load-carrying platform supported by a cushion of low-pressure air (up to 1 psi). ACV's appear to have significant capabilities for off-road operation in regions of soft surfaces. These correspond to soils having poor load-carrying capabilities, as well as snow, mud, water, and ice-covered surfaces. Because the ACV is not dependent upon a firm surface for traction and support, operational capabilities can be retained through the all-weather environment. Additional capability is provided by the potential utilization of

rivers and other waterways as alternate routes for logistic support. At the same time, the disadvantage of ACV's must not be overlooked. In terms of performance capabilities, this means relatively poor gradability and poor maneuverability. In terms of economy of operation, disadvantages include high first cost, increased maintenance complexity, and increased fuel consumption, as compared with wheeled vehicles of conventional design.

A great deal of ground effect research and development has been conducted under sponsorship of the Army and Navy as well as by private industry over the last five years. The purpose of this study is to apply the results of all these previous research programs and the knowledge of this contractor to the possible application of vehicles using the ground effect phenomena to the off-road logistic operations of the U.S. Army.

1.2 MISSION

Pending the development of firm mission requirements for an off-road ACV, this study is based on an "assumed mission", utilizing the general logistics doctrine of the Combat Development Agency. The assumed mission in its most basic form is:

"To provide transportation for logistical movement of personnel, general cargo, and small weapons in support of tactical units."

Unstated, but strongly inherent in the above mission, is the capability to provide logistical support in all terrain and environmental situations occupied by tactical units. A further implication of the assumed mission is the conduct of both line-haul and local area operations.

At this point in the program, no decision is required as to the make-up of transportation units, for instance ACV or mixed equipment, or to the existing units which would be replaced or supplemented (present organization tables indicate missions similar to the assumed mission of this program are carried out by: Transportation Light Truck Company, TOE 55-17; Transportation Cargo Carrier Company (Tracked), TOE 55-27; and Transportation Tactical Carrier Company, TOE 55-47).

Inasmuch as logistic operations will utilize roads and other prepared routes where available (see Section 1.1), it is mandatory that the

off-road ACV be compatible with on-road operations. Indeed, it must be itself capable of efficient on-road operation. This implies certain characteristics of width, maneuverability, and speed. It is fundamental to the program that increased off-road capability may be gained at the expense of costs, but not at the expense of certain minimum limits for on-road operations.

Because of the generalized wording of the assumed mission statement, payload-range-speed parameters for the program must be selected in an arbitrary manner. The Operations Research Monitoring Group (GEM) has approved the following parameters for purposes of this study only (Reference 1):

- | | | | |
|----|----------------------------------|-------------------|--|
| 1. | Rated payload | 0-5 tons | (all weights in pounds and short tons) |
| 2. | Range | up to 250 miles | (statute miles to be used throughout) |
| 3. | Maximum speed required (on-road) | 40 miles per hour | |

In order to simplify the analysis, the range parameter will be divided into discrete intervals: 25, 50, 100, and 250 miles. For off-road operations, maximum range may be associated with reduced payloads, but no less than one-half rated payload. It is assumed that exclusively on-road operations may utilize payloads up to 50 per cent above rated payload.

Other performance capabilities required in the assumed mission include limited amphibious capability, i. e., river crossings, and operations in flooded areas, including marshes and swamplands. Off-road mobility should be approximately the same as that of tactical vehicles of the field army. Mobility should also be sufficient to provide all-weather operation over line-haul routes, on-road or off-road.

The off-road vehicles considered in this program must be transportable by rail, ship, and air. Phase I air transportability (immediate availability for operation) in C-130 and C-141 type aircraft will be considered.

The operational environment associated with the assumed mission is given in the next section, with the resulting vehicle performance, physical parameters, and design philosophy in the following section.

For the cost/effectiveness analysis later in this program, the assumed mission will simulate the logistics requirements for a division of the type field army, in the combat zone. This mission is similar to that discussed in U.S. Army Transportation Combat Development Group Project TCCD 61-83 (SP), "Modernization of the Field Army Transport Service Through Employment of AC-1 and HC-1 Aircraft" (Reference 2).

For each combat zone division of the type field army, the following daily requirements are set forth in FM 101-10 (Reference 3).

Per division per day - short tons

	Class - I	II & IV	III	V	Total
Enters combat zone	98	147	231	203	679
Moved to army forward supply points	76	102	130	199	507
Moved to division area	58	66	50	195	369

Average distances (flying distances) are 100 - 150 miles from the rear boundary of the combat zone to the army forward supply points, and 50 miles from the army forward supply points to division supply points. (Shorter range distribution operations within the division area may also be considered.) The flying distances should be multiplied by 1.5 for approximate road distances. (For purposes of this study, use of off-road routes will not cause significant reduction in route distance from road distances.) The cost of building bridges or roads around obstacles will, however, be included in the analysis.

1.3 OPERATIONAL ENVIRONMENT

In order to adequately define the operational environment for the off-road logistics vehicle, the entire range of environmental parameters must be considered. The statement of the basic assumed mission is given in the preceding section. The determination of a corresponding operational environment is best accomplished in an operations research oriented study by a combination of known physical parameters which

combine in the various route segments. For simplification, only a single assumed operational environment will be used in the performance analysis phase of this program. Modifications to the assumed environment and the effect of engineer support, in route preparation and maintenance, will be applied in the cost/effectiveness analysis phase of the program.

The assumed mission environment, then, is a combination of anticipated environmental situations which together make up the operational environment of the assumed mission. Obviously, all the parameters will not be present in all the missions, and the proportions of various environmental situations will vary. For the performance analysis, specified percentages of total mission mileage will be assigned to each environmental situation, and it can be shown that these are consistent with previous environmental analyses.

The assumed mission environment has been developed from the contractor's previous experience and from reports of a number of Army environmental operations: desert, tropical (wet), subarctic, and arctic. For purposes of this study, the assumed mission environment is as given in Table 1. The percentage of total mission mileage apportioned to each environmental situation is assumed to be applicable to both line-haul and local area movement over all the selected ranges: 25, 50, 100, and 250 miles. (In the determination of cost/effectiveness later in the program, the effects of varying degrees of route preparation and engineer support will be considered.) The assumed mission environment outlined in Table 1 includes nine separate environmental situations ranging from two-lane surfaced highway to swamp areas and rocky stream beds.

Correlation of the assumed mission environment with some commonly used environment categories is shown in Table 2. The same environment elements applied in Table 1 are here apportioned in four common environment categories: Standard (temperate zones), Polar, Desert (hot or temperate), and Tropical(wet). The percentage of each environment situation in each category is again based on an evaluation developed from previous program experience, particularly the extensive analysis in "The Domain of the GEM" (Reference 4). A similar basis is used for determining the percentage of total world-wide potential operation areas in each of the four environment categories.

TABLE 1
ASSUMED MISSION ENVIRONMENT

Route Segment		Percentages of Total Mileage
1.	Graded rough road with gradients less than 15 per cent	15
2.	Ungraded open grassland, obstacles less than 3 feet, rolling grades less than 30 per cent	20
3.	River crossing, banks 30 - 50 per cent, current 3 knots	5
4.	Uncleared forest, trees spaced 15 - 30 feet, undergrowth to 2 feet, occasional stumps up to 3 feet	10
5.	Swamp area, scattered vegetation, only occasional obstacles over 2 feet, space between tree roots over 15 feet	10
6.	Two-lane surfaced highway, soft shoulders, bank less than 30 per cent	25
7.	Open desert with some dunes, gradients on dunes up to 30 per cent	5
8.	Dry stream valley, twisting floor bed with rocks up to 2 feet, rocky banks	5
9.	Rain soaked, graded dirt road, wheel ruts up to 2 feet deep, obstacles require periodic leaving road and returning up and down grades 30 per cent	5
		<hr/> 100

TABLE 2
WORLD-WIDE OFF-ROAD MOBILITY ENVIRONMENT

Route Segment	Percentage Mileage by Environment Category			
	Stand.	Polar	Desert (wet)	Tropical
1. Graded rough road with gradients less than 15 per cent	10	40	40	10
2. Ungraded open grassland, obstacles less than 3 feet, rolling grades less than 30 per cent	20	(1/2 snow covered) 40	25	15
3. River crossing, banks 30 - 50 per cent, current 3 knots	5	5	--	10
4. Uncleared forest, trees spaced 15 - 30 feet, undergrowth to 2 feet, occasional stumps up to 3 feet	10	--	--	15
5. Swamp area, scattered vegetation, only occasional obstacles over 2 feet, space between tree roots over 15 feet	5	--	--	15
6. Two-lane surfaced highway, soft shoulders, bank less than 30 per cent	40	--	20	20
7. Open desert with some dunes, gradient on dunes up to 30 per cent	--	--	10	--
8. Dry stream valley, twisting floor bed with rocks up to 2 feet, rocky banks	5	5	5	5
9. Rain soaked, graded dirt road, wheel ruts up to 2 feet deep, obstacles require periodic leaving road and re-turning up and down grades 30 per cent	5	10	--	10
	100	100	100	100
Percentage of Total Mileage in Each Environment Category	50	10	15	25

Distribution of Environmental Category - World Wide

<u>Environment Category</u>	<u>Percentage of World</u>
Standard	50 per cent
Polar	10 per cent
Desert	15 per cent
Tropical (wet)	25 per cent

It can be seen from Table 2 that certain of the environmental situations would not be anticipated in some of the environment categories. It should also be noted that rough mountain areas (approximately 20 per cent of world's land area) are not included in either Table 1 or Table 2. The mobility of all vehicles (even tactical vehicles) in these regions is so poor as to preclude extensive mobilized ground operations. Application of the ACV concept to logistic operations would not improve this situation.

The summation of anticipated operational environments in various categories in Table 2 is a significant input to the assumed mission environment in Table 1. For preliminary design and performance specifications, the values given in Table 1 are considered to provide an adequate environmental framework.

In addition to the natural operating environment, the military operational environment also has an effect on the mobility system. Factors such as nuclear blast, and radiological and biological warfare environments, do not directly influence the performance specification for the off-road ACV, but they must be considered in the final phase of the study following the determination of vehicle characteristics.

1.4 DESIGN AND OPERATION PHILOSOPHY

Sections 1.1 - 1.3 contained discussions of the general doctrine for off-road logistic mobility, the assumed mission for the off-road ACV and the assumed operational environment of the off-road ACV. From this background, it is possible to develop a design and operation philosophy for use in establishing preliminary design and performance specifications.

The significant input elements from the foregoing discussion, and the parameters of ACV design and performance which they influence,

are given in Table 3. As might be expected, a number of parameters are influenced by more than one input.

The numerical values of parameters from each input are given in Table 4. These are listed under the six primary elements contained in Sections 1.1 and 1.3. The parameters given in Table 4 are discussed below:

1. Speed - from the doctrine of concurrent mobility (with tactical vehicles), and considerations of on-road operations, a maximum speed (on-road) of 35 mph is sufficient. For meeting the desired objectives of the assumed mission, a maximum speed (on-road) of 40 mph has been selected. Speed requirements for off-road movement are not given. This is a parameter in which performance should be optimized.
2. Payload - desired range 0 - 5 tons. Consideration should be given to all densities and sizes of military cargoes falling within this weight range.
3. Range - from concurrent mobility, a desired range of 300 miles (on-road) is given, although this is beyond the capability of most present tactical vehicles. For the assumed mission, range values of 25, 50, 100, and 250 miles were chosen, with some payload reduction permitted for off-road operations over the longer ranges.
4. Size - from considerations of both on-road operation (width) and air transportability (C-130 aircraft limiting), a maximum width of 10 feet is specified. Under the provisions of AR 705.35, a lateral clearance of 5 inches is required; therefore the limiting vehicle width in configuration for air transport is 10 feet less 10 inches, or 110 inches (Reference 6). A reduction in width to 8 feet would be desirable (for on-road operation).

TABLE 3
INPUTS TO DESIGN AND OPERATION PARAMETERS

Input Section Element	Influences
<u>1.1 Doctrine</u>	
A. "concurrent mobility" (with tactical vehicles) (Reference 5)	- speed, range, maneuver- ability, ground clearance, gradability, water per- formance, ground pressure
B. all-weather operation	- ground pressure and trac- tional system
<u>1.2 Mission</u>	
C. system capability	- payload, speed, range, water performance
D. on-road operation	- size, maneuverability, speed, weight
E. transportability	- size, weight
<u>1.3 Operational Environment</u>	
F. environmental situation	- size, maneuverability, ground clearance, grad- ability, ground pressure and tractional system, water performance

TABLE 4
DESIGN AND OPERATION PARAMETERS

Input Element (see Table 3)	"Concurrent Mobility" (with tactical vehicles)	All-Weather Operation	System Capability	On-Road Operation	Transport- ability	Environmental Situation
Parameter						
1. Speed-max (mph)	35	--	40	35	--	--
2. Payload (tons)	--	--	0-5	--	--	--
3. Range (s. miles)	300	--	25, 50, 100, 250	--	--	--
4. Size - width (ft)	--	--	--	10 (max)	9'2" for 10' wide	15', obstacle separation
5. Size - height (ft)	--	--	--	11 (max)	8'6" for 9' high	
6. Gradability (%)	60	--	--	--	--	30 (50 on banks)
7. Maneuverability	23-foot turn radius	--	--	equivalent to truck or truck/trailer	--	to avoid trees and rocks, etc.
8. Ground clearance (ft)	1.5	--	--	--	--	3.0

TABLE 4 (continued) DESIGN AND OPERATION PARAMETERS						
Input Element (see Table 3)	"Concurrent Mobility" (with tactical vehicles)	All-Weather Operation	System Capability	On-Road Operation	Transport- ability	Environmental Situation
9. Water perfor- mance	7 mph, with 12" waves	--	floatable and self- propelled	--	--	floatable and progress against 3-knot current
10. Ground pressure and tractional system	less than 7 psi	continuous forward movement when wet	--	--	--	forward movement in swamps, sand, snow, and mud
11. Gross weight (tons)	--	--	--	20	--	--
12. Empty weight (tons)	--	--	--	--	15	--

5. **Size** - for on-road operation, the maximum height (height) is 11 feet, with normal load. For air transportability, the limiting height (C-130 aircraft) is 9 feet (less 6 inches per AR 705-35). This specification may be met by an empty vehicle with cargo and cab roof, etc., "knocked down", but no major disassembly.
6. **Gradability** - for concurrent mobility with tactical vehicles, primarily tracked vehicles, a gradability of 60 per cent is desirable. From the assumed mission environment, a maximum steady grade of 30 per cent is required (river banks to 50 per cent up to 10 feet high). Since the air cushion type vehicle is significantly penalized by excessive gradability requirements unless heavily powered, and since it has other trafficability advantages, limitation of steady gradability requirements to 30 per cent may be justified. Towing or winching may be utilized to negotiate short, steep grades.
7. **Maneuverability** - from concurrent mobility, a minimum turn radius of 23 feet would be desirable. For on-road operation, the proposed ACV should be compatible with other traffic so that maneuverability (turning, stopping) should be at least as good as that of a loaded truck-semitrailer combination. For off-road operation, the ability to avoid boulders, trees, and other obstacles at the highest maintainable speed is desirable. Based on knowledge of present ACV state of the art, there appears to be a strong case for some kind of ground contact (the wheeled ACV). Further discussion of this important point is given below.
8. **Ground clearance** - from concurrent mobility concepts, a ground clearance of 18 inches is desirable. From evaluation of the assumed operational

environment, a clearance of 3 feet (36 inches) between the hard structure and the ground has been chosen. For an ACV vehicle using flexible extensions, the clearance of the lower extensions could be much lower; probably 4 to 6 inches free clearance can be used as a design criterion.

9. Water performance - limited amphibious capability is mandatory, primarily for river crossing and negotiating open stretches of swamps and marshes. The vehicle must be floatable and seaworthy in waves up to 12 inches. It should be able to move against a 3-knot current. A water speed of 7 miles per hour would meet the concurrent mobility concept. The ACV is expected to have inherently satisfactory water performance, with speed capability determined by the provisions for an overwater drive system.
10. Ground pressure and tractional system - a low ground pressure is inherent in the ACV concept; thus bearing strength of soils is less of a problem than for wheeled and tracked vehicles. In open areas of swamps, and on level snow, mud, and sand surfaces, this low ground pressure reduces the load on the traction elements. This is also true of wet and flooded surfaces, so that all-weather capability is enhanced. The 7-psi ground pressure criterion for concurrent mobility concepts is not applicable. For operations through areas with many light obstacles, as in forest undergrowth and some swamp regions, additional traction over that obtainable from the basic ACV lift-propulsion air system may be needed. Here, again, there may be an advantage to some kind of ground contact or tractional system. This is discussed below.

11. Gross weight - in regard to operational limitations, a gross weight of about 20 tons is the maximum for on-road operation. In areas with poor road systems, load limits of 10 - 15 tons (and less) apply to many bridges. Within the desired payload range of 0 - 5 tons, a gross weight of less than 15 tons can probably be achieved, using present state-of-the-art concepts.
12. Empty weight - this is limited, by air transportability requirements, to less than 15 tons (C-130 aircraft). Also, the size limitations for air transportability (10-foot width maximum), combined with the present over-all state of the art, will probably limit empty weights to less than 8 - 10 tons. The resulting maximum gross weights would then be on the order of 12 - 15 tons (see preceding item).

On the basis of preliminary analysis of the factors discussed above, the Operations Research Monitoring Group (GEM) has approved (for use of this program) the selected values given in Reference 1 for the following parameters:

Speed (max)	40 miles per hour
Payload	0 - 5 tons
Range	25, 50, 100, 250 miles (payload 2-1/2 tons at 250 miles)
Size (max width)	10 feet (9 feet 2 inches in air transport configuration)
Gradability (max)	30 per cent
Ground clearance (max)	3 feet to "hard" structure
Water performance	Limited amphibious capability

On-road performance

**On-road utilization mandatory,
parameters except width
and speed not specified.**

With these values in mind, it is necessary that the vehicle's maneuverability and tractional systems be reviewed before proceeding to the development of performance characteristics, accomplished in the next chapter. The questions of "wheels" vs. "no ground contact" and flexible extension vs. no flexible extension should therefore be resolved at this stage.

Considering the feasibility of flexible skirts, it is apparent from any review of the state of the art that some form of flexible skirts will be applied. The significant reduction in power required to surmount a given obstacle size is the predominant factor in this choice. Reduction of dust and spray is also advantageous.

At the time of the first BAARINC GEM state-of-the-art report, Reference 7, the development of skirts was in its infancy and the practical application of skirts was yet to be proven. Progress since then has been sufficient to provide a basis for application to the off-road ACV. It is anticipated that further results of tests on vehicles with skirts will be reported in other ACV research programs prior to the completion of this study.

For purposes of the performance analysis in the next chapter, it will be assumed that skirted configurations are an inherent part of the overall basic design.

The question of adding wheels or other ground contact systems to the off-road ACV is more difficult to answer. The advantages of some sort of ground contact are: better maneuverability on narrow routes, including better roadability; and increased traction on grades and where light obstacles must be brushed aside. The disadvantages of ground contact are: increased complexity, weight, and rougher riding qualities.

Probably the overriding considerations here are the requirements for 30 per cent gradability on-road utilization. At the speeds being considered (up to 40 miles per hour), it is probable that total power requirements for lift and propulsion (traction) will be significantly less for a vehicle utilizing wheels for support and traction than for

an air-cushion-supported/air-driven system, even a fully skirted system. In addition, the requirement for maneuvering compatibility with other vehicles on the road dictates a quick response and a precisely controllable system. This can be achieved more easily by use of a ground contact than by a pure air-cushion system.

There are, however, many situations when a ground contact such as a wheel is definitely undesirable. These would include navigation of water surfaces (increased drag), movement through mud (resistance from stickiness) and movement over low obstacles less than 2 feet in height (large shock loads from contact with rocks or stumps).

There is no easy solution. For the initial development of the performance model, it must be assumed that the vehicle weight can be supported entirely on wheels, or entirely on the air cushion, or possibly shared between these two means. The added complexity is a known disadvantage, but this must be borne until such time in the program when adequate results are available to make a choice.

Some discussion of how a dual support system would function is given in the following. For on-road operation, economy and maneuverability would probably dictate full vehicle weight on the wheels. If the road is muddy, some of the weight could be shifted to the air cushion to reduce sinkage, while maintaining traction and steering control with the wheels. At the other end of the operational environment spectrum, river-crossing operations might be best accomplished with all weight on the air cushion, and perhaps a small water propeller, while relying on wheel traction to help in ascending steep banks.

Extension of this thinking to the assumed mission environment of Section 1.3 is illustrated in Table 5. Using the same environmental situations as in Tables 1 and 2, the relative surface firmness and a corresponding distribution of weight between wheels and air cushion are given. The values given in parentheses are appropriate to specialized environment categories or situations, while the underlined values are the ones generally associated with the given environment situation. The numerical values for "Percentage Weight on Wheels" are only conjectural at this point in the analysis, and may be taken as representative of four modes of operation, i. e. :

"100 per cent on wheels" means wheels for support, traction, and maneuvering

"40 - 80 per cent on wheels"	means wheels used for traction and maneuvering, with the air cushion carrying a large proportion of the weight
"5 - 20 per cent on wheels"	means almost all weight carried on the cushion, but wheels may be used for traction and/or maneuvering
"0 per cent on wheels"	means operation without ground contact except possibly for maneuvering.

Table 5 is not intended to solve the problem of "wheels" vs. "no ground contact". By combination with the material in Table 2, however, it can be seen that about 40 - 45 per cent of the off-road vehicle total mileage will be accumulated in conventional on-road operation (route segments 1 and 6), and about 25 per cent of the mileage will be accumulated in other environmental situation where precise maneuverability is required (route segments 4, 5, 8, 9). The important result here is that pure ACV's, without ground contact, will probably not be sufficiently maneuverable or economical to meet the over-all requirements of the U.S. Army for an off-road logistic vehicle. Thus the more complex vehicle configuration, including wheels or some other form of ground contact, must be considered through at least the preliminary phases of the performance analysis.

Finally, the over-all operation philosophy applied to this study is that the air cushion logistic vehicle (the off-road ACV) must function as part of the over-all Army logistics system, and not as a special-purpose vehicle.

Concepts of unit organization, maintenance, personnel requirements and cargo handling procedures should conform as nearly as possible to conventional motor transport operations. Obviously the advantages of the ACV concept should be exploited in the improvement of off-road mobility, both in area coverage and in speed. No attempt will be made, however, to invent entirely new tactics or new concepts of logistic operations. For operational, logistic, and cost parameters which are not unique to the ACV, commonly accepted values from military planning documents and costing estimates will be used.

TABLE 5 (Provisional)
TERRAIN FIRMNESS AND OFF-ROAD ACV DESIGN PHILOSOPHY

	Terrain Description	Terrain Firmness	%Weight on Wheels
1.	Graded rough road with gradients less than 15 per cent	<u>hard</u> *	<u>100</u>
2.	Ungraded open grassland, obstacles less than 3 feet, rolling grades less than 30 per cent	<u>soft</u> (hard in desert)	<u>10-20</u> (desert 40-80)
3.	River crossing, banks 30-50 per cent, current 3 knots	<u>soft</u> and <u>water</u>	(40-80 banks) <u>0</u> water
4.	Uncleared forest, trees spaced 15 - 30 feet, undergrowth to 2 feet, occasional stumps up to 3 feet	<u>hard</u> (assumed , but not always)	<u>40-80</u>
5.	Swamp area, scattered vegetation, only occasional obstacles over 2 feet, space between tree roots over 15 feet	<u>soft</u> and <u>wet</u>	<u>5-20</u> <u>0</u> where open spaces
6.	Two-lane surfaced highway, soft shoulders, bank less than 30 per cent	<u>hard</u>	<u>100</u>
7.	Open desert with some dunes, gradients on dunes up to 30 per cent	<u>soft</u>	<u>40-80</u>
8.	Dry-stream valley, twisting floor bed with rocks up to 2 feet, rocky banks	<u>hard</u> and <u>water</u>	<u>40-80</u>
9.	Rain soaked, graded dirt road, wheel ruts up to 2 feet deep, obstacles require periodic leaving road and returning up and down grades 30 per cent	<u>soft</u> and <u>wet</u>	<u>40-80</u> (5-20 where flooded)

* "hard" implies unimpeded movement of conventional wheeled vehicle without special equipment.

CHAPTER II

THE OFF-ROAD DETERMINISTIC MODEL

2.1 METHOD OF APPROACH

The heart of this operations research study concerns the application of state-of-the-art concepts to the development of the characteristics and capabilities of an ACV capable of providing the Army with improved off-road mobility in logistic operations. Accordingly, the off-road logistic operation defined in Table 1 is used to represent the assumed mission environment and design parameters in keeping with the current state of the art in the ground effect field. A new approach, using recently acquired information on wheeled vehicles, is also used in the determination of vehicle characteristics using the air cushion principle to "off-load" the wheels.

These considerations have formed the basis in developing the "off-road" deterministic model, which has been programmed for use on the CDC 160 digital computer. A major feature of this model is the capability of varying a wide range of parameters so that new situations and modified input data can be analyzed quickly and consistently. This feature has included the ability to change the environment as well as the design parameters.

The primary output of the off-road ACV computer analysis is the payload carried for any particular situation. In determining this payload, the design and performance characteristics of the ACV vehicle are defined, based on the original assumptions. For example, length of the final vehicles is determined, a useful value for comparison with other logistic vehicles.

The results obtained in the final analysis represent realistic characteristics of an air cushion vehicle that can be readily compared with other typical motor transports. These results will also provide a basis for estimating the costs of an ACV as developed in the next chapter.

2.2 MODEL DESCRIPTION

In order to provide a detailed description of the model, Figure 1 has been drawn. This figure is essentially the computer flow chart, the notation of which is as follows:

A	ratio of cushion area to vehicle planform area
B	per cent of lift horsepower required for stability
HP_L	design lift horsepower
HP_P	design propulsion horsepower
HP_{L_n}	lift horsepower required for each environmental segment, n
HP_{P_n}	propulsion horsepower regained for each environmental segment, n
HP_P/T	horsepower required per unit thrust of propelling force
$(HP/T)_n$	horsepower required per unit thrust of propelling force in a particular environmental segment, n , of the out-bound leg (loaded)
K_1	resistance of the wheeled system as a fraction of the weight in the wheels
N	weight of structure per unit area
R	total range traveled (round trip distance)
$(R/\frac{R}{2})_n$	the per cent of range in each environmental segment, n , for both outbound and inbound legs
S	cushion planform area
S_v	planform area of the vehicle

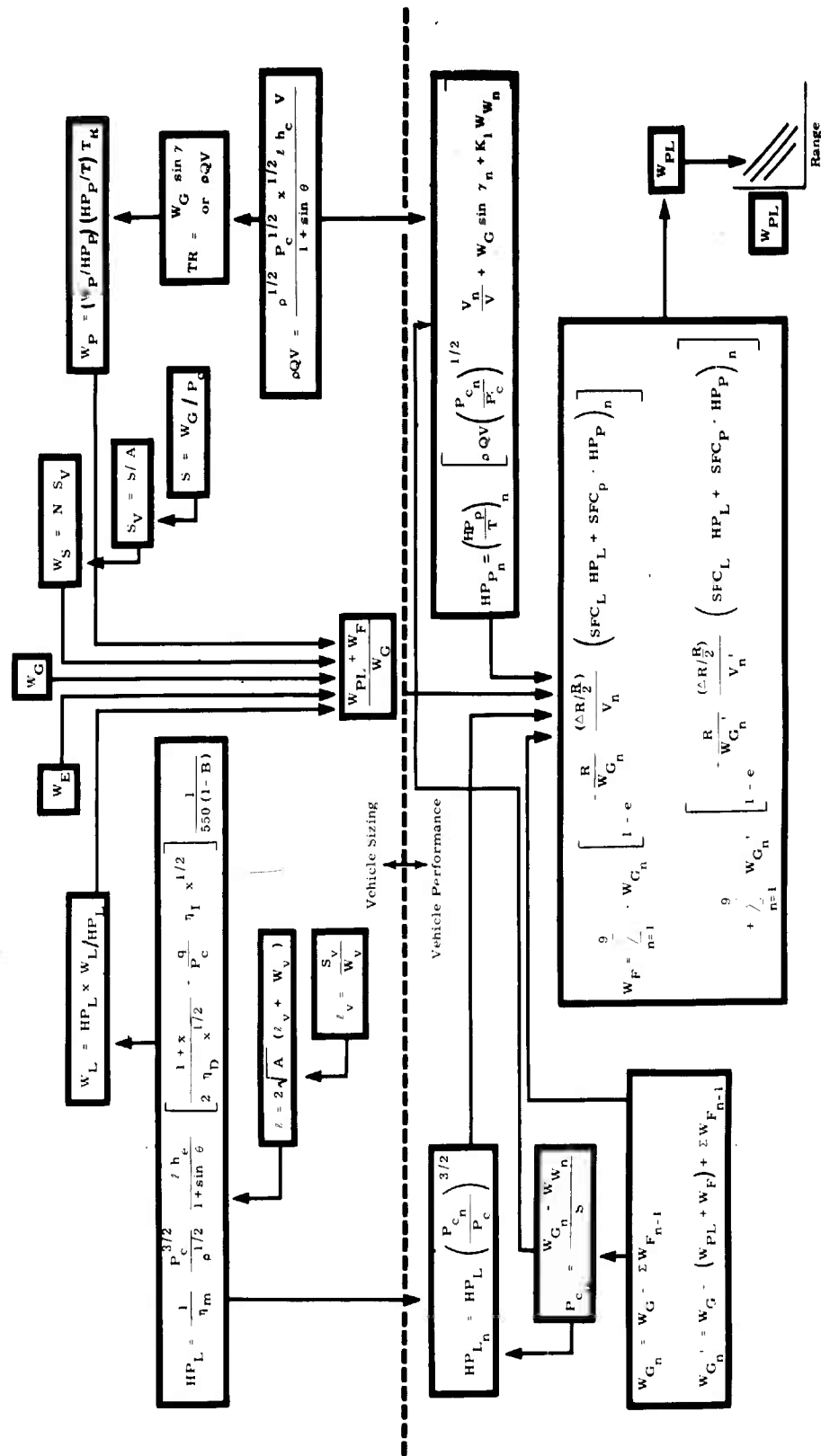


Figure 1 Off-Road ACV Deterministic Model

SFC_{L_n}	lift engine specific fuel consumption for each environmental segment, n
SFC_{P_n}	propulsion engine specific fuel consumption for each environmental segment, n
T_R	propelling thrust required
V	maximum design forward velocity of the vehicle
V_n	forward velocity of the vehicle in each range segment, n
W_E	weight of equipment (including wheels and suspension system for the wheeled ACV)
W_G	initial gross weight of the vehicle
W_F	weight of fuel
$W_{F_{n-1}}$	weight in all segments up to the n th
W_{G_n}	gross weight of the vehicle in each outbound environmental segment, n
W_{G_n}	gross weight of the vehicle in each inbound segment, n
W_L	weight of lift engines
W_L/HP_L	weight of lift engines per unit horsepower
W_P	weight of propelling engines
W_P/HP_P	weight of propelling engines per unit horsepower
W_{PL}	weight of payload
W_S	weight of structure in the vehicle

W_{W_n}	per cent of vehicle weight on the wheels in each segment, n
e	exponential
h_e	effective height of the air curtain
l	vehicle peripheral length (measured at center line of jet)
l_v	length of the vehicle
p_c	maximum cushion pressure
p_{c_n}	cushion pressure in any segment, n
q	dynamic pressure
q/p_c	speed parameter
x	jet thickness parameter
γ	maximum angle of grade which must be traversed
γ_n	average grade angle negotiated in each environmental segment, n
η_D	lift system ducting efficiency
η_I	engine intake efficiency
η_m	mechanical drive efficiency
θ	deflection angle of annular jet measured from the vertical
ρ	air density

The top portion of the flow chart defines the relationships used for vehicle sizing. The results indicate the weight of payload and fuel which can be carried by a vehicle. For a particular vehicle gross weight, the following parameters are defined:

1. Equipment weight
2. Structural weight, a function of gross weight and cushion pressure
3. Lift system weight, a function of lift system characteristics and efficiencies and the cushion pressure
4. Propelling system weight, either as a function of propulsion to negotiate the maximum grade or as a function of the maximum velocity requirements, whichever is greater.

The weight of all the items required for a particular vehicle size is thus determined, with the remainder made up of payload and fuel.

The bottom portion of the chart is used to determine the fuel used for various ranges, and the corresponding payload. This calculation sums the weight of fuel used in each environmental segment of the assumed mission, based on the particular characteristics of the vehicle in the particular segment. A form of the Breguet range equation is applied with particular values of required horsepower, dependent upon the terrain and whether or not wheels are used. The gross weight used for each outbound segment is in effect the weight at the beginning of the segment, while the gross weight on the inbound segment is the weight at the end of the segment. In effect, the outbound segment is evaluated from the full gross weight, while the inbound segment uses the empty weight as a starting point, with calculations proceeding from the base to the point where the payload has been delivered. In reality, the average weight for each segment should be used. This technique results in pessimistic fuel weights on the outbound leg and optimistic fuel weights in the inbound leg. Although the effects are compensating to an extent, the results should be somewhat pessimistic, since the fuel used in the outbound leg is larger than that used in the inbound leg. In other words, there is some inherent reserve. The payload is the weight available after the fuel has been consumed.

The model has the capability of utilizing variation in practically every input variable. The following section will indicate the value of the parameters used in the computer analysis and the reasoning for selection. The results will indicate the capabilities of a particular system. Some variations will be shown, defining effects of changing particular parameters.

2.3 GENERAL DESIGN PARAMETERS

In any systems performance analysis of hypothetical vehicles, many assumed values are required to estimate that performance. In this study, two types of parameters are defined.

First, there are the parameters used consistently throughout the analysis. These are based on the hypothetical capability of the state of the art and are listed in Table 6.

Comments On Use of Parameters

Values for deflection angle, jet thickness, and speed parameters are all based on data in Reference 8 .

Cushion pressure is a maximum value, assumed within the capabilities of the 1965-1975 state of the art, current values being between 70 and 80 pounds per square foot. It must be realized that this maximum value is present only at the start of the journey.

Effective operating height is based on the use of flexible extensions which will allow a maximum hard structure clearance of 3 feet.

Maximum vehicle width is limited by transportability consideration (110 inches).

The cushion area ratio is based on what can be expected in 1965. The value for the wheeled ACV is lower by 0.10 because the wheels were considered to be outside the skirt.

Efficiencies are typical of what can be expected at the present time.

Power required for stability is a function of hover height.

Structure weight is considered typical for ACV's operating in an environment demanding rugged, but lightweight, frames. From Figure 2, it will be seen that in the size range under consideration, the study value is in keeping with the state of the art.

The vehicle is sized either to traverse a 30 per cent grade or to attain a maximum speed of 40 miles per hour on the road. In all cases, the former criterion was more severe, so that in reality the vehicle would be capable of exceeding the maximum speed requirement if equipped to harness the additional power.

TABLE 6
ASSUMED DESIGN PARAMETERS

Parameter	Air Cushion ACV	Common to Both	Wheeled ACV
Deflection angle of annular jet, θ , deg.		35	
Jet thickness parameter, x		.85	
Speed parameter, q/p_c		.1	
Cushion pressure, p_c , lb/sq ft		90	
Effective operating height, h_e , ft		.5	
Maximum vehicle width, w_v , ft		9.17	
Ratio of cushion area to vehicle area, A	.87		.77
Lift system duct efficiency, η_D		.8	
Engine intake efficiency , η_I		.9	
Mechanical drive efficiency, η_m		.85	
Lift power required for stability, Bh_e		.05 h_e	
Structure weight, W_s , lb/sq ft		20	
Maximum velocity required, V , mph		40	

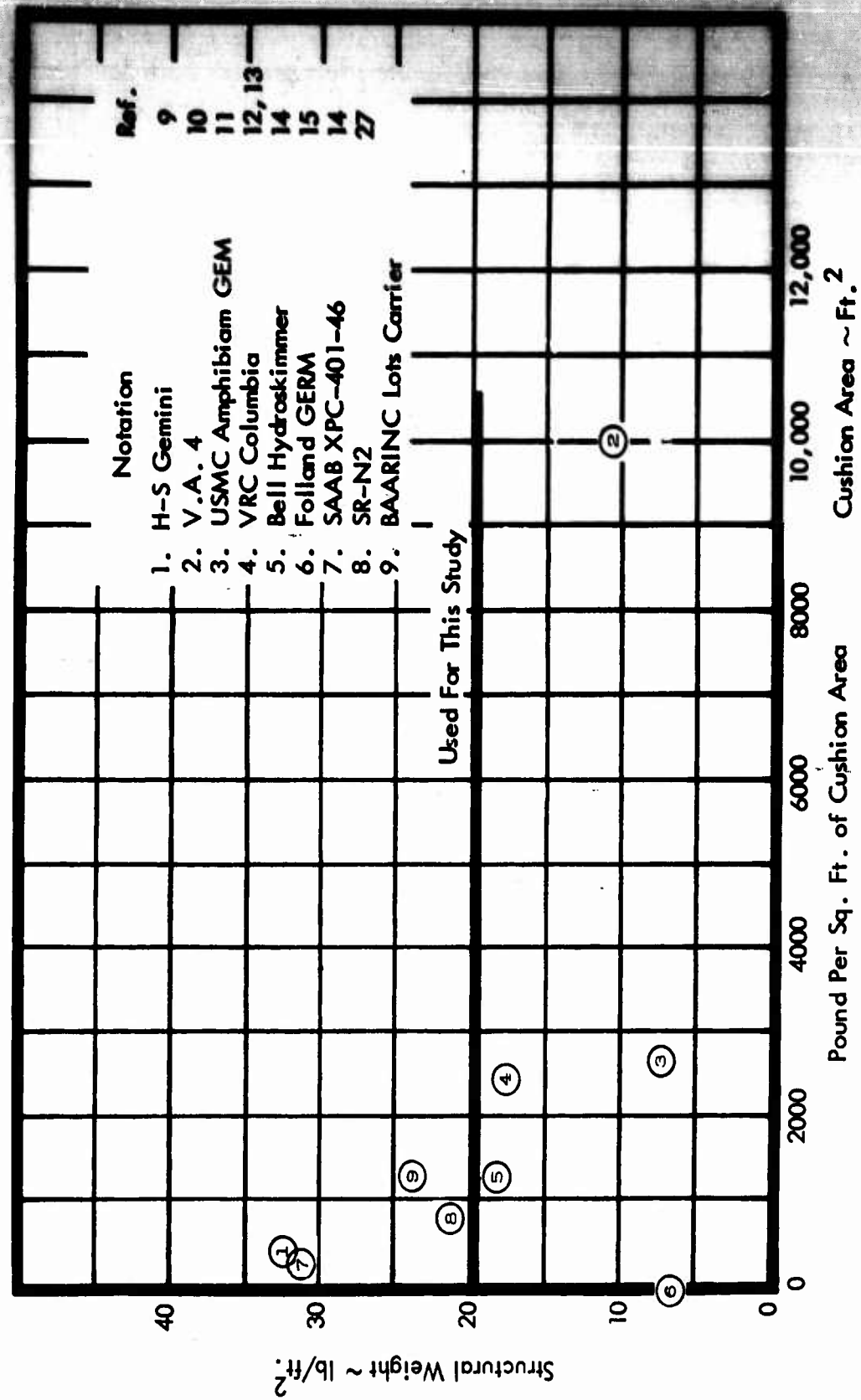


Figure 2. Structural Weight

The second group of parameters are varied in the analysis, with estimates made for the most appropriate values of each and variations from these to indicate their sensitivity. These parameters are listed in Table 7.

A 20,000-pound gross weight was chosen as nominal for this particular case, having a payload-carrying capability somewhere within the 0 to 5-ton requirement for the study.

The equipment weight was assumed to be 1,000 pounds for the pure ACV, a typical value which represents 5 per cent of the nominal gross weight and which has been used in previous studies (Reference 16). To this value was added the suspension system for the wheeled ACV including the drive system, based on data in Figure 3. Lightweight systems are assumed since the wheels will not support the full weight of the vehicle on a continuous basis.

The specific fuel consumption was estimated based on data in Table 8 and summarized in Figure 4. Some thought was given to the effect of running gas turbines at less than rated power. Figure 5 shows that a 50 per cent reduction in power results in only a 20 per cent increase in fuel consumption. If, as is reasonable to suspect at this point, the power system is made up of a number of smaller engines, any number of which can be shut down when not required, it is apparent that this factor will have little effect in the analysis.

The specific weight of the power plants is of vital importance. Data shown in Figure 6 represent typical values of current systems which include engines, transmission, propeller drive system, and lift-fan drive system. From these data, the specific value of fan turbine engines was determined. To account for differences resulting from employing reciprocating and diesel engines, data in Figure 7, based on the data in Table 8, were used.

These data include weight of power plant only, and provide the basis for the ratios used in Figure 6.

The propelling tractive effort for propeller systems is straightforward and is shown in Figure 8. However, the development of tractive effort for wheeled vehicles requires a complete system analysis. One factor which enters into the evaluation is the horsepower required to produce a pound of locomotive force. It is dependent upon the speed of the vehicle and upon the condition (wheel contact with the ground), whether

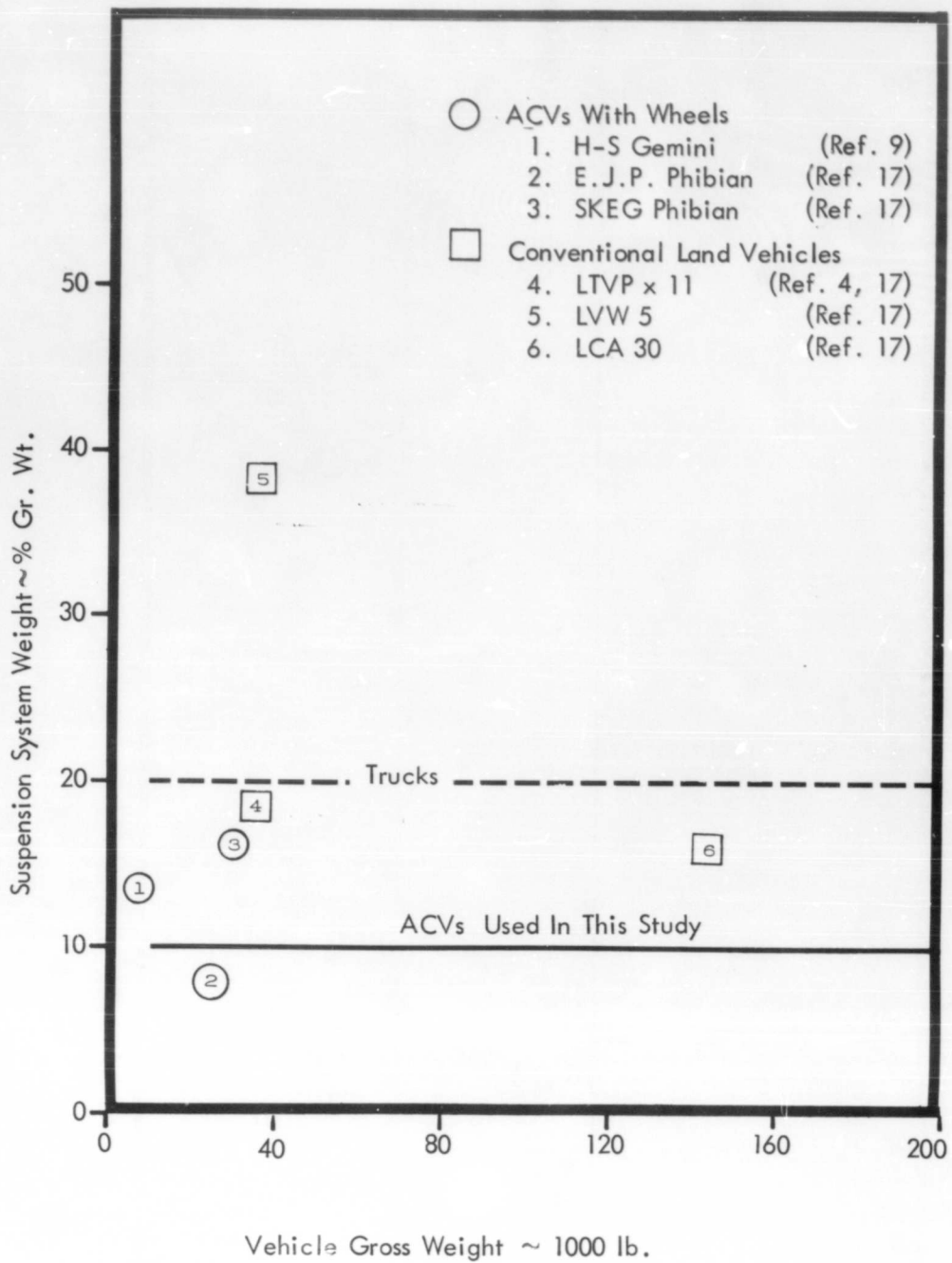


Figure 3. Suspension System Weights

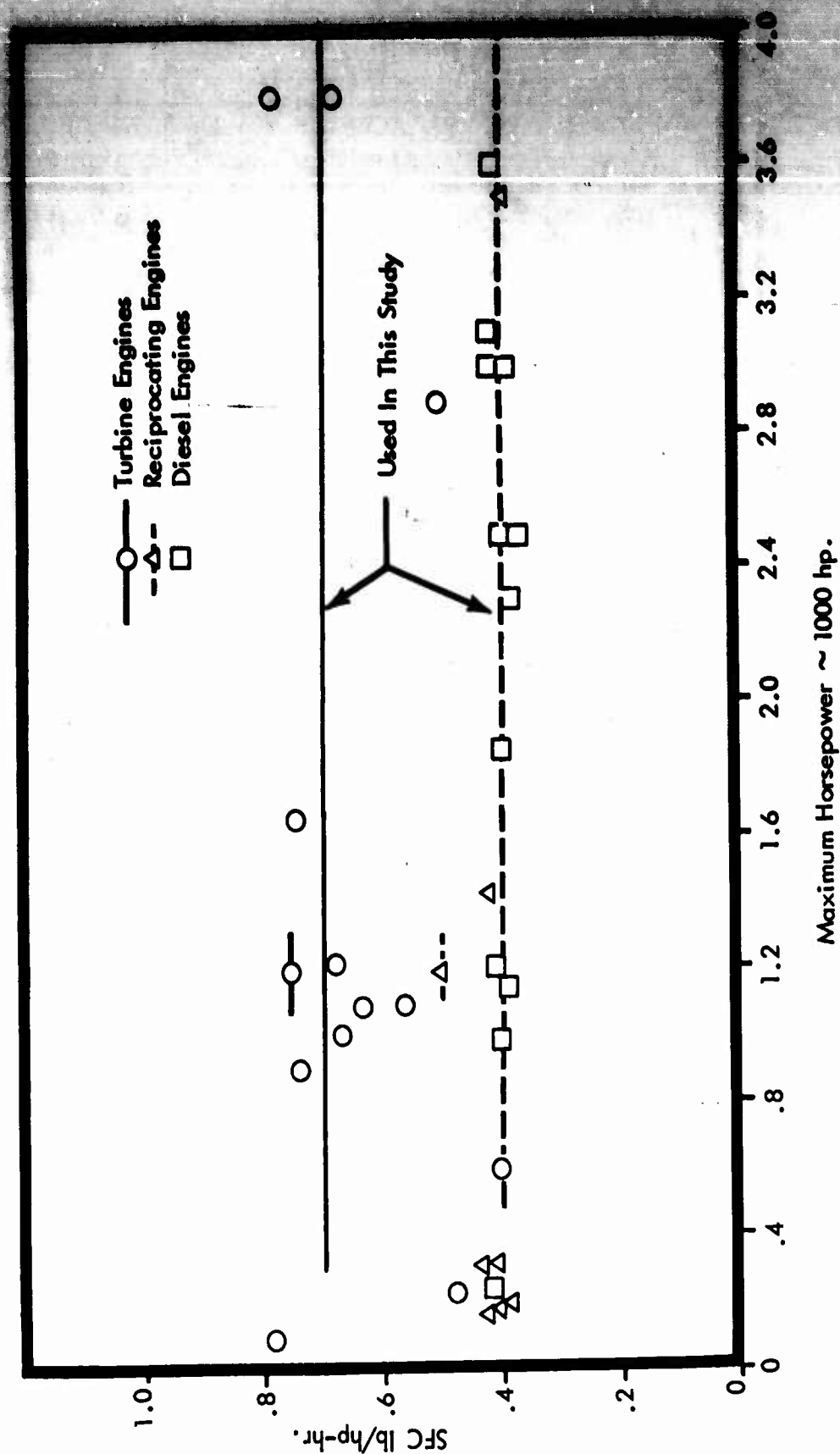


Figure 4. Specific Fuel Consumption

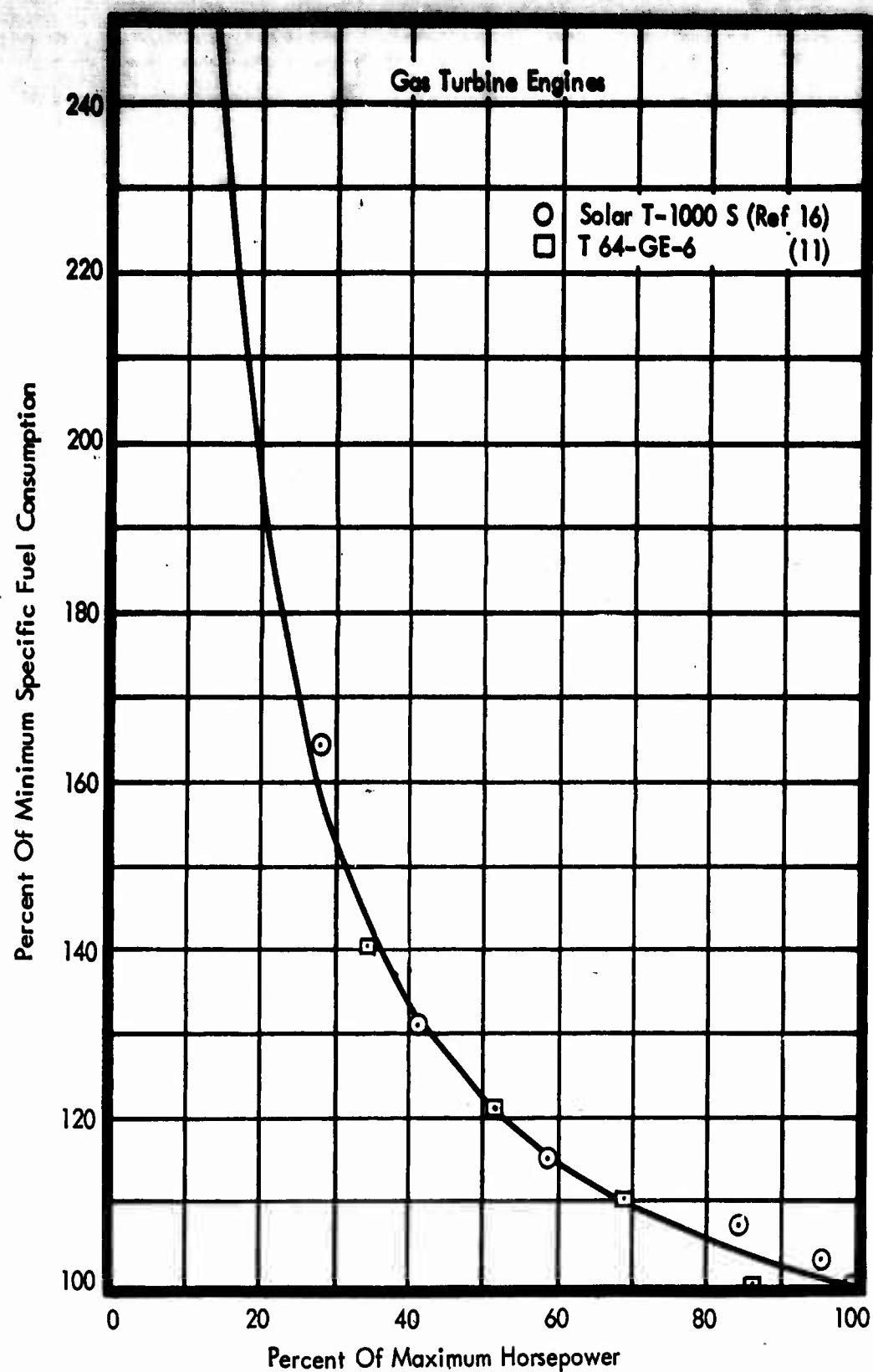


Figure 5. Increase In Rate Of Fuel Consumption Due To Decreased Horsepower

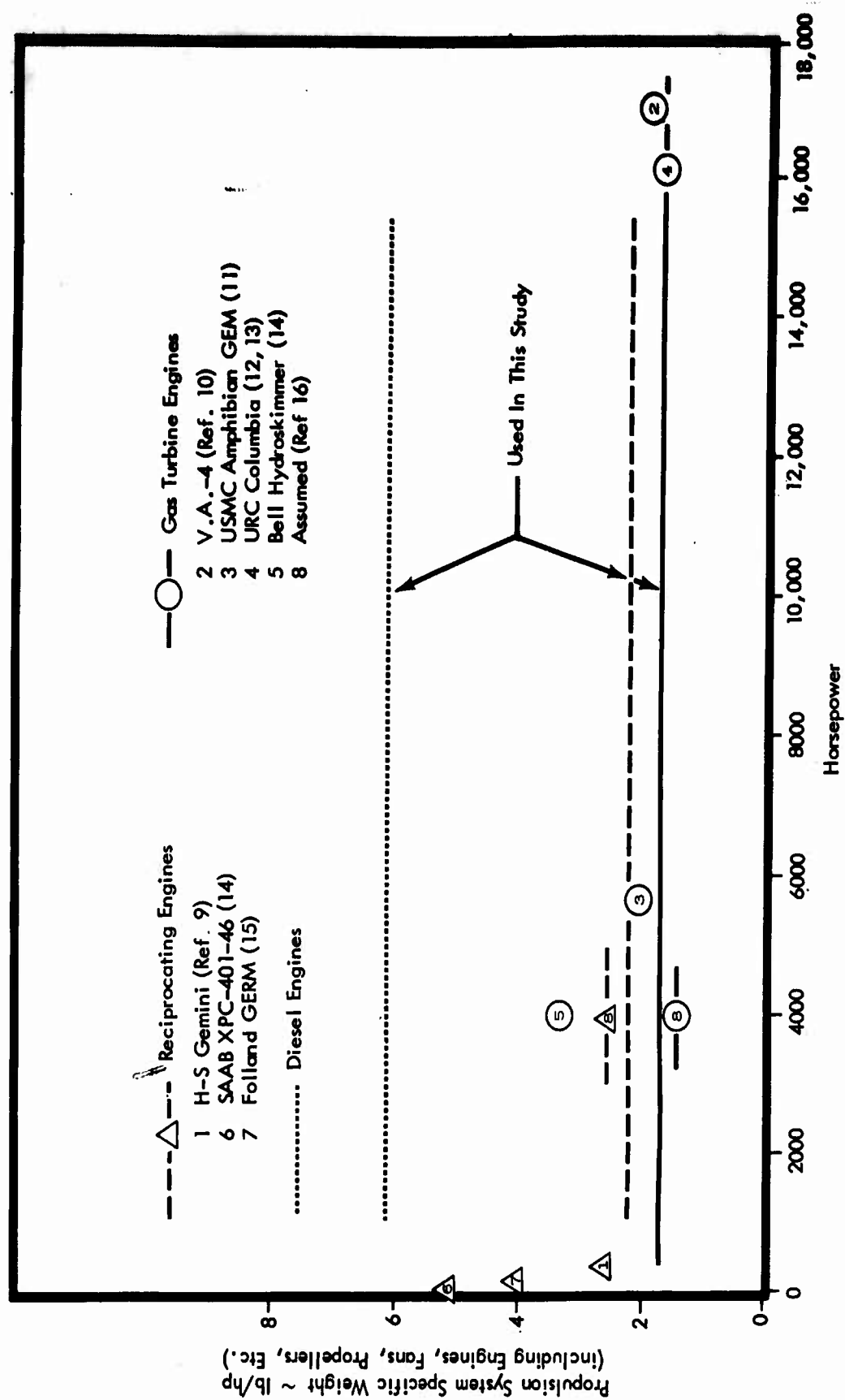


Figure 6. Propulsion System Specific Weight

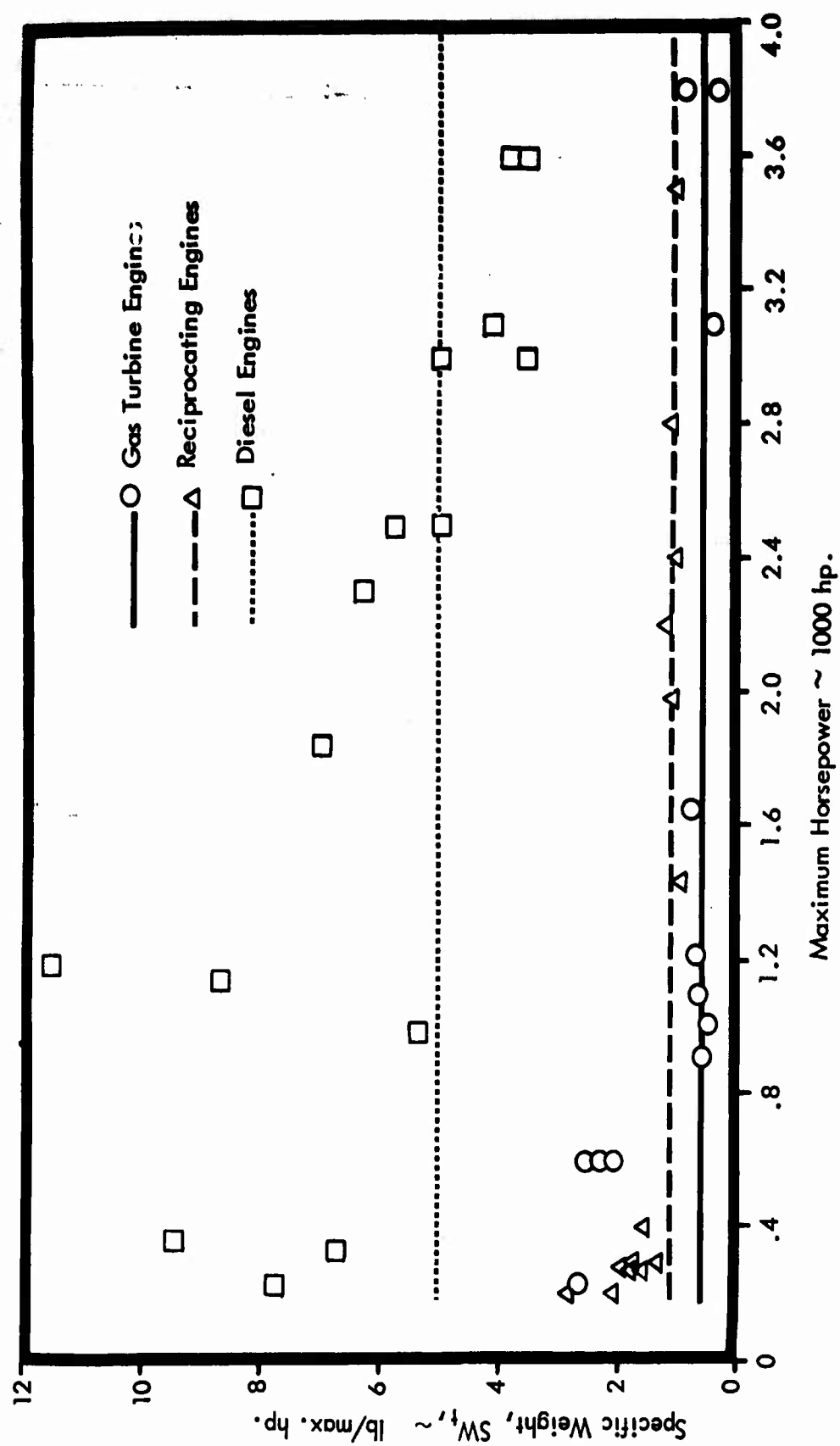


Figure 7. Engine Specific Weight Of Power Plants

- 1. Folland GERM (Ref. 15)
- 2. Doak Model 16 (Ref. 26)

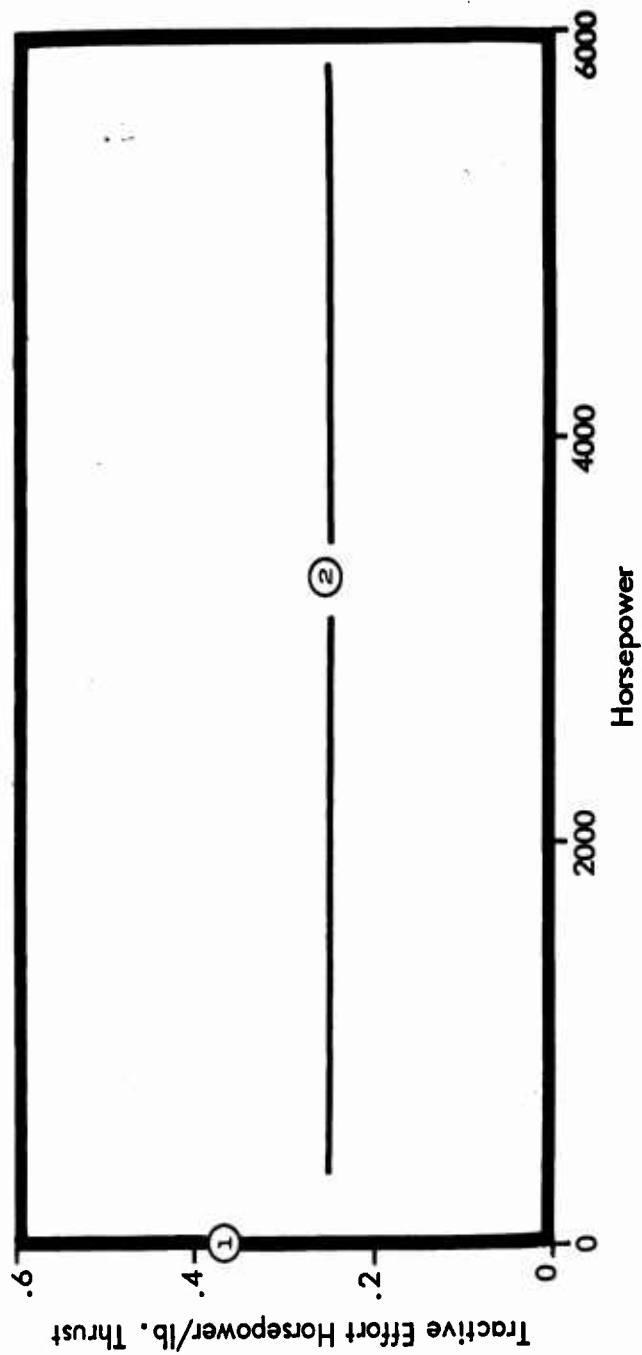


Figure 8. Propeller System Tractive Effort

TABLE 7
VARIABLE DESIGN PARAMETERS

Parameters	Nominal Values	Variations
<u>Gross weight</u> , W_G , lb	20,000	12,000 - 24,000
<u>Equipment weight</u> , W_E , lb		
Pure ACV	1,000	none
Wheeled ACV (includes wheels and suspension system)	3,000	2,200 - 3,4
<u>Specific fuel consumption</u> , lb/hp-hr		
Gas turbines	.7	.5 - .8
Reciprocating and diesel engines	.4	none
<u>Specific weight of power plants</u> , lb/max hp		
Gas turbines	1.7	1.4 - 2.0
Reciprocating engines	2.2	2.2 - 2.5
Diesel engines	6.1	
<u>Tractive effort</u> , hp/lb thrust		
Pure ACV	.25	.2 - .4
Wheeled ACV	.03	.01 - .10
<u>Weight on the wheels</u> , per cent W_G		
Pure ACV	0	none
Wheeled ACV (average over entire mission)	50	0-100

TABLE 8
ENGINE DATA

Designation	Max HP	SFC lb/hp _c . hr	SWt lb/hp _m	Ref.
<u>Gas Turbine Engines</u>				
Pratt & Whitney FT 12	3800	.78	.27	18
Bristol Proteus MK 1270	3800	.68	.84	18
Lycoming T 55	1650	.74	.73	18
Lycoming T 53	1220	.68	.74	18
Solar Saturn 10 mv.	1100	.63	.86	18
T-58-GE-6	1050	.67	.33	26
T-58-GE-8	1250	.57	.29	26
General Electric T64-GE-6	2900	.50	.37	11
G. M. Truck Turbine	225	.55	2.6	19
Ford Auto Turbine	600	.40	2.0	20
Solar	600	.40	2.5	20
Orenda	600	.40	2.3	20
Lycoming T 53-L-1	901	.735	.53	21
Lycoming T 53-L-5	1005	.664	.46	21
Bulworth Brill Mk 2	100	.78	1.15	22
Saturn T-1000	1250	.56	.76	22
Assumed Values		.75	1.4	16
<u>Reciprocating Engines</u>				
Wright 3350 Turbo Compound	3500	.391	1.0	23
Wright Cyclone Radial	1425	.42	0.9	23
Franklin 425 Helicopter	300	.43	1.3	23
G. M. V-8 Cast Iron	200	.40	2.8	19
G. M. V-8 Aluminum	205	.39	2.0	19
P&W R2000CB16	2400	--	1.0	23
Wright R 3350 745 c/8 BA1	2200	--	1.2	23
Wright R3350 975 c/8 CA1	2800	--	1.08	23
Bristol Hercules 234	1980	--	1.08	23
Lycoming GSO 580	400	--	1.5	23
Lycoming GO 480	280	--	1.55	23
Continental	265	--	1.8	23
Rolls Royce L V8	310	.42	1.64	22

TABLE 8 (continued) ENGINE DATA				
Designation	Max HP	SFC lb/hp _c . hr	SWt lb/hp _m	Ref.
Jaguar XK 3.8 alloy blk.	265	.42	1.88	22
Ford (U. S. A.) N	280	.42	3.69	22
Armstrong Star Sapphire	190	.42	3.19	22
Assumed values	--	.50	2.5	16
<u>Lightweight Diesel Engines</u>				
Fiat 20 X - 560	3600	.41	3.6	18
Maybach MD 872	3600	.41	3.7	18
Napier Deltic T18-37K	3100	.42	4.1	18
Mercedes Benz MB-518B	3000	.39	3.5	18
Mitsubishi 24WZ-AK	3000	.41	4.9	18
Fairbanks Morse 38A6 3/4T	2500	.38	5.7	18
Napier Deltic T18-39K	2500	.39	4.9	18
Napier Deltic T18-27K	2310	.38	6.2	18
Napier Deltic T18-25K	1850	.39	6.9	18
Detroit Diesel Twin 12V-71T	1200	.41	11.5	18
Napier Deltic T9-29K	1155	.39	8.6	18
Curtiss-Wright 12V-142	990	.40	5.3	18
International Tractor	375	.39	9.4	25
G. M. 6V-71	240	.41	7.7	24
G. M. 12V-71	340	--	6.7	24

the wheel is spinning or not. A second factor which must be considered is the resistance of the tire to motion. This is a function of the weight on the wheels and the condition of the ground contact. For a hard surface, the resistance is the force required to deflect the tire. However, if the tire sinks into the soil, the resistance includes the force required to compact the soil and the bulldozing force resulting from pushing the soil in front of the wheel as well as the force required to deflect the tire. The third factor which must be considered is the weight on the wheels. The best situation, as far as utilizing minimum fuel, is to carry as much weight on the wheels as the soil will support without deflection. However, in order to maintain the speeds of the wheeled ACV, it was deemed necessary to provide considerable lift in some of the more rugged environments, to enable the ACV to maintain speed and to reduce the wear and tear on the vehicle

For this reason, some nominal value of weight on the wheels was used in some of the environments. A list of values used for the wheeled ACV follows:

Environment	Horsepower per unit thrust (hp/lb)	Resistance to motion due to wheels (per cent weight on wheels)	Weight on wheels (per cent gross weight)
1	.063	.02	100
2	.047	.02	50
3	.031	0	0
4	.016	.02	50
5	.031	.30	5
6	.094	.02	100
7	.063	.50	80
8	.016	.02	50
9	.025	.30	5

Design horsepower per pound of thrust for traveling up a 30 per cent slope = .03 .

These values represent the typical situation employed. There may be some other considerations which will affect these values in actual practice. In general, these can be resolved by reducing the average

slope assumed in each environment or by some other way qualifying vehicle performance. The preliminary analysis to follow will show the justification for the particular parameters chosen.

2.4 WHEELED SYSTEM DESIGN CRITERIA

Basic Principles of Wheel Thrust

A wheel develops thrust by virtue of the shear strength of the surface it is running on. Thrust attained is a result of compacting the soil in a mainly horizontal direction, the compaction resulting in wheel slip.

Maximum thrust attained is when maximum soil strength is achieved, at a specific value of slip. Beyond this point, thrust available reduces with increasing slip.

Different soils have different shapes to the thrust-slip curve depending on soil characteristics.

Resistance to Motion

Apart from aerodynamic resistance to motion, a wheel, when running on a hard surface with negligible sinkage, has only the resistance resulting from tire deflection. This shows itself as an effectively reduced tractive effort for a given power developed.

When operating on soft surfaces where sinkage cannot be ignored, the wheel is subject to tire deflection resistance, a resistance due to vertical compaction of the soil, and a resistance due to "bulldozing" the soil away in front and to either side.

Power Required

The total power required at the engine shaft to drive a wheel is determined from the total resistance to motion and the wheel slip at which the required thrust is being generated. Then:

$$HP = \frac{\text{Total resistance (lb)} \times \text{Speed (mph)}}{\text{Mech. Eff. } (\eta_m) \times 375 \times (1 - i_o)}$$

where

i_o is the slip defined as $\left(1 - \frac{V}{V_w}\right)$

V is vehicle forward speed

V_w is wheel peripheral speed.

The total resistance is the sum of the wheel resistance and the air resistance.

Application to Wheeled ACV's

In conventional wheeled vehicles, the weight on each wheel can be varied only by unloading or loading the vehicle or by using up fuel. The percentage change during any given mission is quite small and is generally neglected in assessing the vehicle capability for negotiating the terrain or route.

As a result, the vehicle wheels are selected for optimum performance in a particular segment of the terrain, frequently indicating that unless the vehicle is of unconventional construction fitted with unusual wheels, the range of surface conditions that it can travel over is strictly limited.

In the wheeled ACV, however, a means is available for varying the weight on the wheels from full weight to no weight. The importance of this becomes clear when it is realized that for some soils, notably sand, the maximum wheel thrust is developed as weight on the wheels increases, while in very soft muds the maximum thrust is developed with little or no weight on the wheels. The wheeled ACV is therefore able to operate at close to optimum conditions in many segments of the environment.

Another aspect of the capability to vary the weight on the wheels is that it is possible to compromise between values of desired vehicle performance over much wider ranges of soil conditions than is possible with conventional vehicles. This, in turn, means that for optimum performance of an overland wheeled ACV, careful consideration must be given to the type of wheels, or maybe tracks, that will provide the very best compromise. Although the capabilities of standard wheels are improved in soft soils by the use of the air cushion principle, a

..
specially designed system would undoubtedly provide notable gains over many routes, particularly those where obstructions are few and far between (marshes, bogs, moorland, grasslands, fens, etc.).

The Deterministic Model Inputs

The particular inputs required in the model for each segment of the route are:

- . Horsepower required per pound of total resistance or total thrust - hp/lb.
- . Wheel resistance due to motion, as a per cent of weight on the wheels.
- . Average weight on the wheels as a percentage of the maximum possible weight on the wheels (note that this is not necessarily the percentage for optimum performance in the given soil due to the need to rise above obstruction frequently).

Evaluation of the Wheeled System Tire Size

To insure that the resultant vehicle be practical for the time frame being considered, it was decided to use existing wheels where possible. From a study of the vehicle layout, sufficient space was allowed around the outside of the annular jet for four wheels up to 5 feet in diameter and with a 1-1/2-foot tire width. Preliminary studies indicate that the large-diameter wheels are a better compromise for tractive effort even though they are bulky, difficult to lift clear of obstructions, and heavy.

The selection of an appropriately sized wheel comparable with conventional truck wheels was achieved as follows: Page 204 of Reference 28 illustrates a method for relating tire diameters, width, contact area, and contact area length, given initial assumptions regarding the $\frac{\text{tire depth}}{\text{tire width}}$, $\frac{\text{tire deflection}}{\text{tire width}}$, and $\frac{\text{ground contact area width}}{\text{tire width}}$.

Figure 9 shows this relationship with the assumptions made in preparing the figure.

Also shown on Figure 9 are a number of truck tires currently in use on Army vehicles, as quoted in Reference 29. It is clear that a

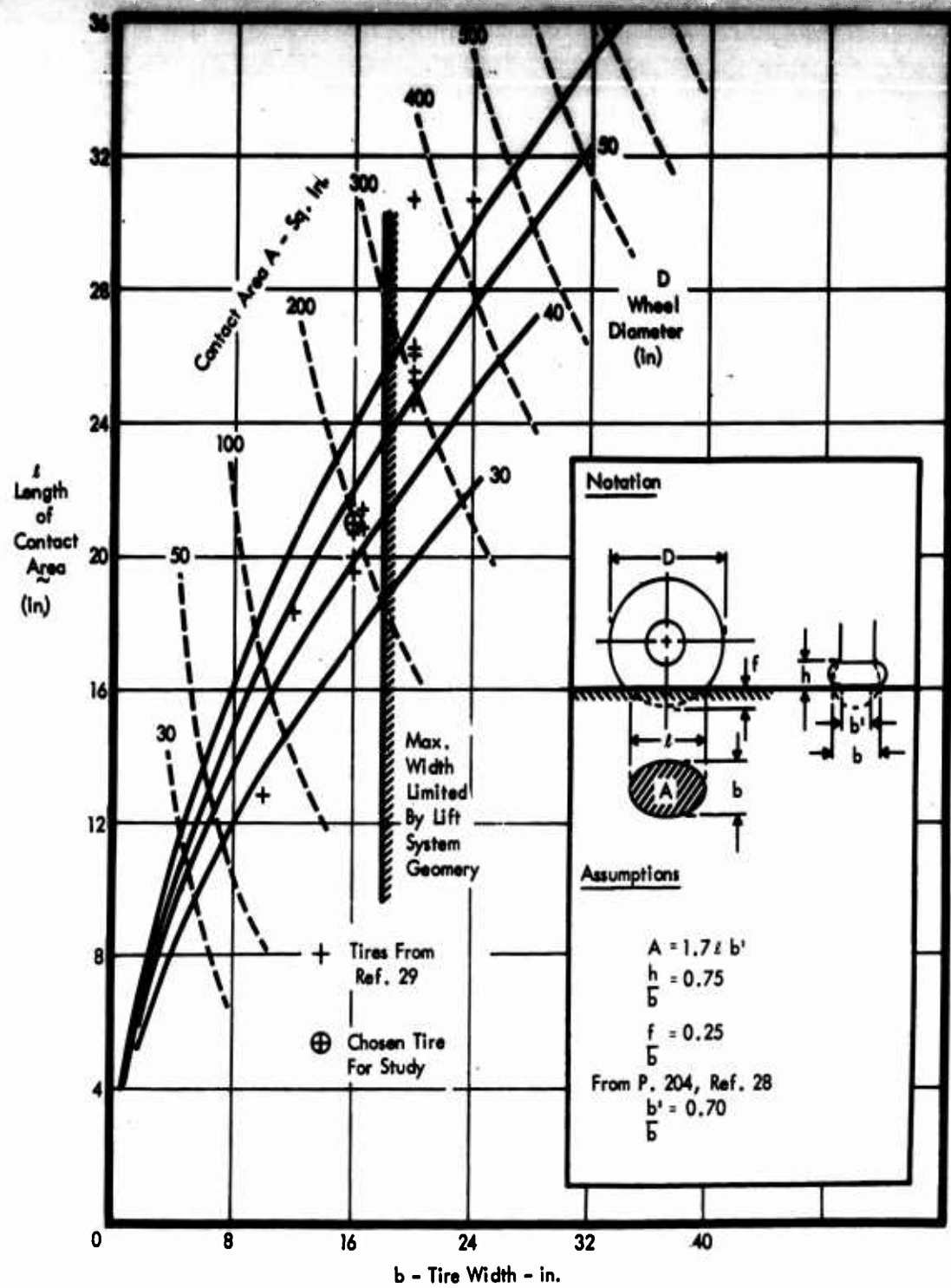


Figure 9. Wheel Parameter Relationships

representative tire exists with a contact area of about 200 square inches, a width of 16 inches, and a contact area length of 21 inches. This tire is used in the rest of the analysis.

Soil Characteristics

In order to develop a consistent analytical program, the average soil conditions in each segment of the environment must be defined. Very little definitive information is available that enables one to determine the parameter values for any given soil. From values given in References 28 and 30, the values of soil parameters in Table 9 were selected as being typical.

Analysis

Soil Thrust: The thrust that can be developed by a given soil is expressed as:

$$H_{i_o} = F(Ac + W \tan \phi)$$

where A = contact area of wheel or track

W = weight on wheel or track

c = cohesive strength of soil, psi

ϕ = angle of friction of soil

F = factor that allows for the fact that slip is not constant along the contact area, but progressive, so that maximum soil strength is developed at only one point. F_{max} is a function of soil characteristics, and occurs at a specific value of $(i_l)_s$ for each soil.

l = length of contact area in direction of motion

F is determined as follows:

$$S_x = \frac{(c + p \tan \phi)}{y_{max}} \left\{ e^{(-K_2 + \sqrt{K_2^2 - 1}) K_1 i_o x} - e^{(-K_2 - \sqrt{K_2^2 - 1}) K_1 i_o x} \right\}$$

TABLE 9
ASSUMED SOIL PARAMETERS

Environment	c	k _e	k	m	K ₁	K ₂	N _c	N	k at b = 16"	F _{max}	i _o at F _{max}	P _s at b = 16"
1	1.60	30°	17.5	6.6	.53	1.0	38	20	7.69	.82	1.7	70.4
2	2.05	25°	6.5	4.7	.47	0.3	26	12	5.10	.85	4.4	59.05
3	6.50	10°	21.0	4.0	.43	0.2	9	2	5.31	.89	5.6	59.10
4	2.05	25°	6.5	4.7	.47	0.3	26	12	5.10	.85	4.4	59.05
5	.25	10°	2.5	2.2	.20	.2	9	2	3.76	.89	5.6	3.21
6												
7	0	35°	0	7.0	0.8	0.2	60	42	7.0	.89	5.6	20.16
8	1.60	30°	17.5	6.6	.53	1.0	38	20	7.69	.82	1.7	70.4
9	.25	10°	2.5	2.2	.20	.2	9	2	3.76	.89	5.6	3.21

where

S = horizontal shearing strength (psi) of ground at x from beginning of ground contact area

c = cohesion strength, psi

ϕ = friction angle

p = ground pressure (assumed constant), psi

i_o = slip, such that actual soil deformation at $x = i_o x = j$

K_1, K_2 = soil slip parameters

(K_1 units of $\frac{1}{\text{inches}}$, K_2 - dimension less)

y_{\max} = max value of function enclosed in () and occurs at j_{opt}

$$j_{\text{opt}} = (i_o x)_{\text{opt}} = \frac{\log_e \left[\frac{K_2 + \sqrt{K_2^2 - 1}}{K_2 - \sqrt{K_2^2 - 1}} \right]}{2K_1 \sqrt{K_2^2 - 1}}$$

$$H_i = \frac{Ac + W \tan \phi}{K_1 (i_o^\ell) y_{\max}} \left[\frac{1 - e^{(-K_2 - \sqrt{K_2^2 - 1}) K_1 i_o^\ell}}{-K_2 - \sqrt{K_2^2 - 1}} + \frac{-1 + e^{(-K_2 + \sqrt{K_2^2 - 1}) K_1 i_o^\ell}}{-K_2 + \sqrt{K_2^2 - 1}} \right]$$

$$F = \frac{H_i}{H_{\max}} = \frac{H_i}{A_c + W \tan \phi}$$

$$F = \frac{\left[\frac{(-K_2 - \sqrt{K_2^2 - 1}) K_1 i_o^\ell}{1 - e^{(-K_2 - \sqrt{K_2^2 - 1}) K_1 i_o^\ell}} + \frac{(-K_2 + \sqrt{K_2^2 - 1}) K_1 i_o^\ell}{-1 + e^{(-K_2 + \sqrt{K_2^2 - 1}) K_1 i_o^\ell}} \right]}{K_1 (i_o^\ell) y_{\max}}$$

and $F_{\max} = F$ at $(i_o^\ell)_{\text{opt}}$

From the soil conditions listed in Table 9, F vs. $(i_0 l)$ has been evaluated and is plotted in Figure 10, clearly defining F_{\max} and $(i_0 l)_{\text{opt}}$. It should be noted that F is almost constant and equal to F_{\max} over a wide range of $(i_0 l)$. It is advantageous to choose the lowest value of $(i_0 l)$ possible, consistent with developing maximum thrust; so when maximum thrust values have been considered, the lower value of $(i_0 l)$ for 99 per cent maximum thrust has been used.

Design Condition

The basic design criterion finally used was that the wheels should be able to generate sufficient thrust to maintain speeds up a 30 per cent grade in environment 2.

Let

N	=	number of wheels
W_G	=	vehicle gross weight
W_w	=	weight supported per wheel
A	=	contact area
F, c, ϕ	=	soil parameters
	=	$\tan^{-1} .30$

then

$$\frac{W_G}{N} \sin \gamma = F_{\max} (Ac + W_w \tan \phi)$$

the chosen wheel - 45 inches in diameter
 - 16 inches wide

wheel operating condition = 200 sq. inches contact area at deflection
 = 4 inches.

$$\therefore \frac{W_G}{N} (.286) = .854 (200 \times 2.05 + W_w \tan 25^\circ)$$

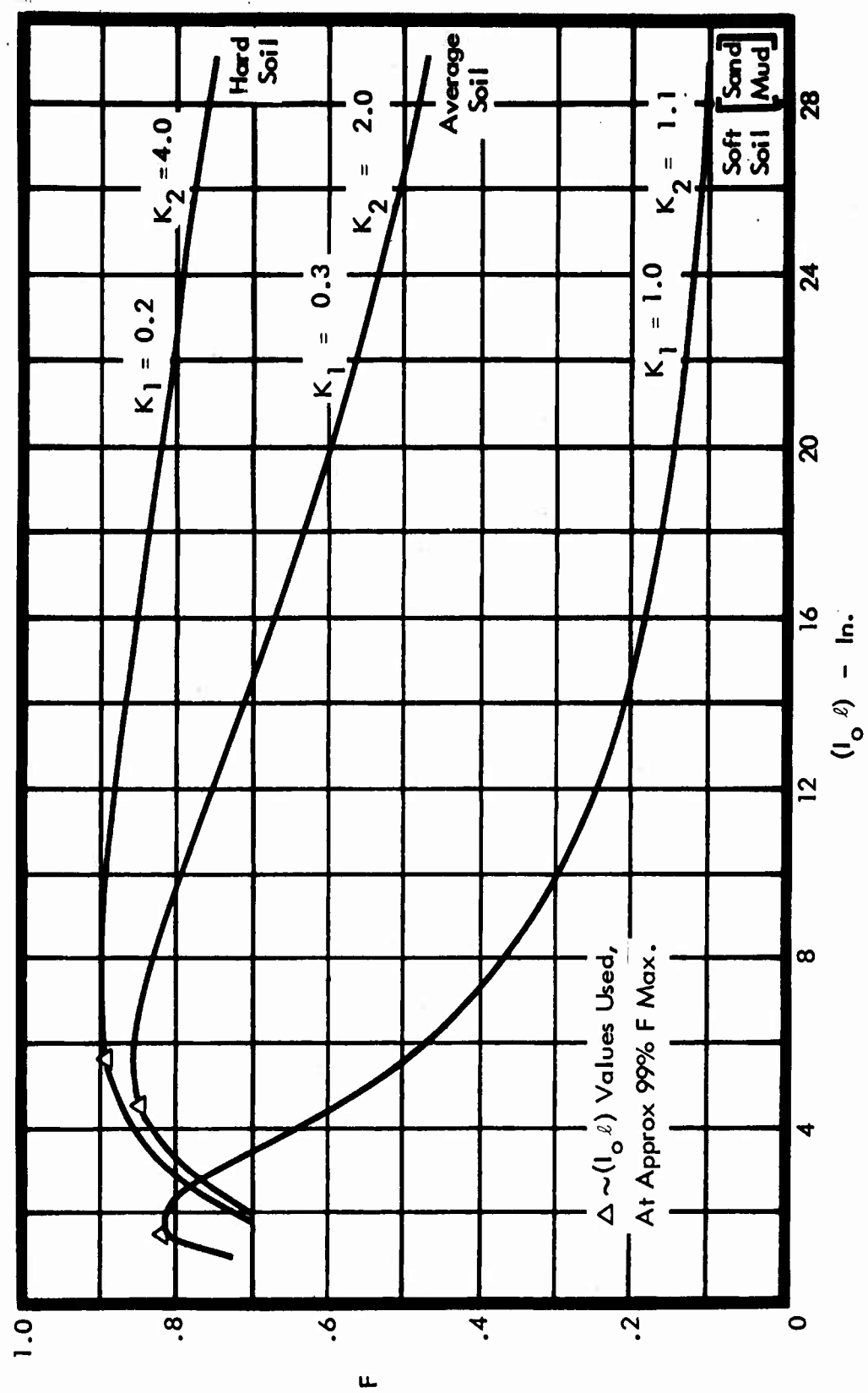


Figure 10. F vs. $(l_0 \ell)$

$$\therefore W_w = .72 \frac{W_G}{N} - 880$$

Now the average ground pressure developed at the design condition is

$$\frac{W_w}{A}$$

$$P_G = .0036 \frac{W_G}{N} - 4.4$$

For the case in question, the safe ground pressure, above which sinkage will occur, is given by:

$$P_s = (cN_c + 1/2 \gamma bN_\gamma)$$

where

P_s = safe ground pressure psi

N_c, N_γ = constants depending on ϕ

γ = soil density

b = width (or smallest dimension) of contact area.

For the soil in environment 2, the design wheel

$$P_s = 2.05 \times 26 + 1/2 \times .06 \times 16 \times 12$$

$$= 53.3 + 5.75 = 59.05 \text{ psi}$$

From the design condition

$$P_G = .0036 \frac{W_G}{N} - 4.4$$

and for $P_G \geq P_s$

$$\frac{W_G}{N} \geq 17.600 \text{ lb, well outside the range of size considered in this study.}$$

Hence, the design condition is correctly evaluated with the chosen wheel when motion resistance of the wheel is neglected.

This ground pressure is balanced by the sum of the tire inflation pressure, p_i , and the tire carcass strength, p_c , i. e., $p_g = p_i + p_t$, and remains constant for a vehicle of a given gross weight.

Figure 11 shows the variation of W_w with $\frac{W_G}{N}$ for several design contact areas.

Wheel Sinkage or Flotation

Wheel sinkage has a profound effect on motion resistance and on the basic tire design that may be most suitable for a particular route.

If the tire is designed to stay on the surface throughout the route, then, particularly if soft soils are encountered, increasing tire width provides a greater capability.

If a vehicle size or shape is such that it would be impractical to provide a sufficiently wide tire, then some sinkage must be tolerated. In this case, sinkage is minimized by reducing tire width and increasing tire diameter. This, in turn, reduces the motion resistance and the slip and provides a more efficient wheeled system.

Wheel sinkage in the environments must be checked. To do this, the ground pressures that are being experienced must be examined. If the surface strength will permit, it is most economical to operate with full weight on the wheels. If the design value of 200 square inches contact area per wheel at the design loading condition of W_w is assumed to remain unchanged as more weight is put on the wheels, then a pessimistic ground pressure is obtained by taking $\left(\frac{W_G}{N}\right)/200$.

Assuming four wheels and a range of weights from 10,000 pounds to 25,000 pounds, the pessimistic pressure range is from 12.5 to 31.25 psi.

Therefore, from Table 9, it is clear that the soils in environments 1, 2, 3, 4, 6, and 8 will support full weight on the wheels, with negligible sinkage. The remaining soils possess much lower surface strengths.

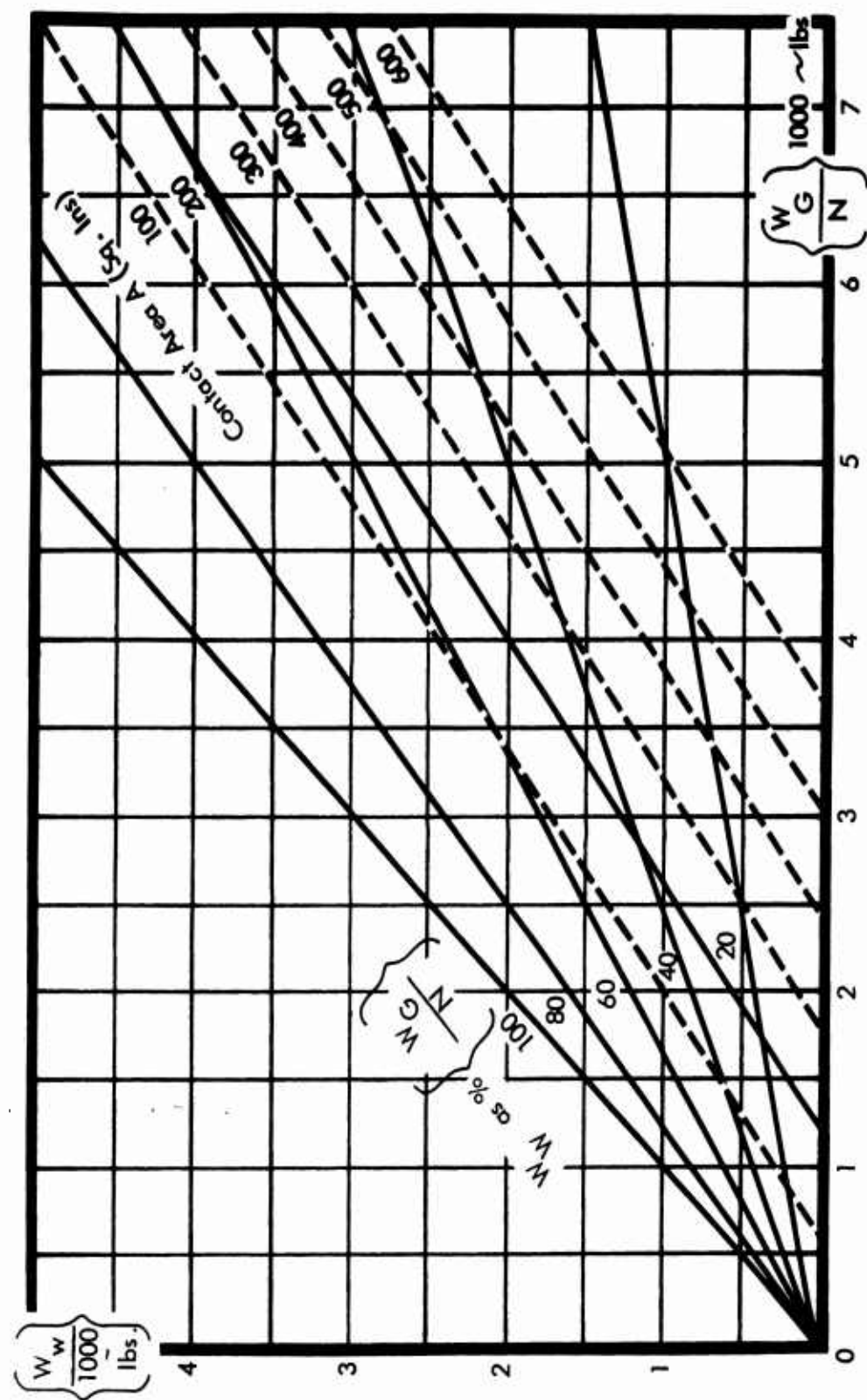


Figure 11. Variation of Design Values of W_w and $\left\{ \frac{W_G}{N} \right\}$ with Contact Area

Environments 5 and 9 have very low values in the region of 3.0 psi, while 7 has a strength of approximately 20 psi.

The variation of ground pressure with weight on the wheels depends very much on the characteristics of the tire. If the tire carcass is very stiff, then the contact area may remain essentially constant and the ground pressure may rise in proportion to the weight. Alternatively, if the carcass is flexible, the ground pressure will remain essentially constant and the contact area will increase with the weight. Figure 12 illustrates the relationship between the ground pressure dictated by the design condition (which remains constant at the design condition value for a fully flexible tire, or rises linearly with W_w for a rigid tire) and the surface strength.

From Figure 12, it is evident that, for all vehicles with greater than 9,000 pounds gross weight, environments 5 and 9 would involve sinkage regardless of the assumptions made about tire stiffness. Environment 7, however, is a little more complex. If p_g remains constant at design value, all vehicle gross weights below 29,200 pounds are capable of flotation. If, however, the area remains constant or $A = 200$ square inches, then flotation can no longer be supported when the weight on the wheels exceeds 4,100 pounds regardless of gross weight. It can be stated, however, that all vehicles whose gross weights are less than 16,000 pounds will be capable of flotation.

Resistance to Motion

Having determined the soil thrust, the design conditions, and those environments in which sinkage must be considered, motion resistance can be evaluated.

Resistance Resulting From Tire Deflection. The best available information on this subject is contained in Reference 30, pages 70, 71, and 72. From this information, it may be assumed that for inflation pressures above 6 psi, $R_i \doteq .02 W_w$.

This is the only tire motion resistance of concern in environments 1, 2, 3, 4, 6, and 8.

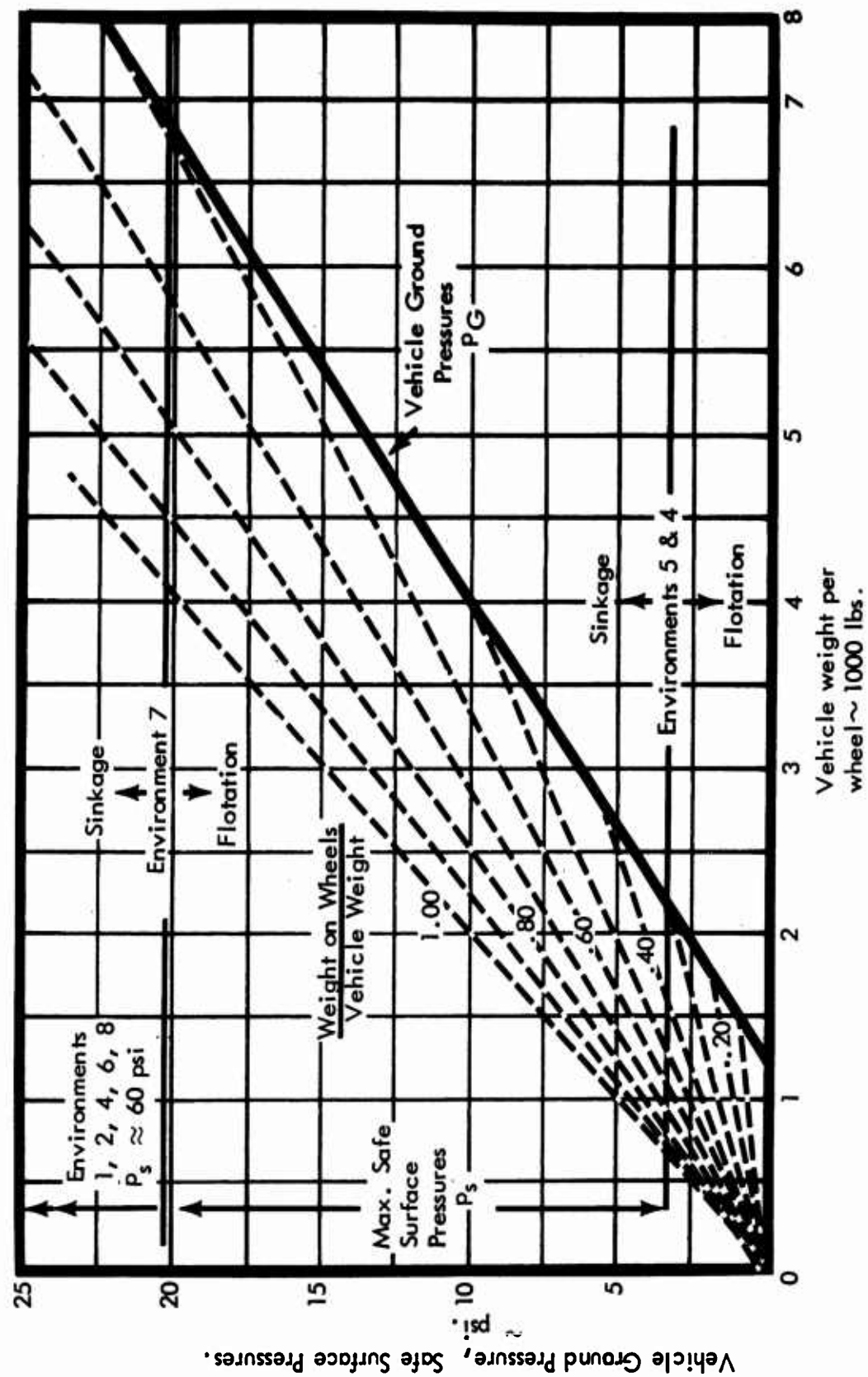


Figure 12. Relationships Between Sinkage, Weight and Environment For Design Condition $A = 200 \text{ Sq. Ins.}$

Resistance Resulting From Work Done on the Soil (Compaction and Bulldozing). The method for evaluating this resistance is that used in Reference 30, Chapter VIII. It has been decided that the wheel was essentially rigid as far as the soil disturbance was concerned, so that equation (31) could be used for compaction resistance; equation (32), for sinkage. Bulldozing resistance is determined from equation (55).

Hence, total wheel resistance resulting from work done on the soil is given by the following expression:

$$R_T = R_c + R_b$$

$$R_c = \frac{\frac{3W}{\sqrt{D}} \frac{2m+2}{2m+1}}{(3-m) \frac{2m+2}{2m+1} (m+1) (Kb) \frac{1}{2m+1}}$$

$$R_b = \frac{b}{2} \left[1 + \frac{\tan \phi}{\tan \alpha} \right] z (2cK_c + \gamma zK_\gamma) + \frac{\pi t^3 (90 - \phi)}{540} + ct^2 \left(\frac{\pi}{180} + \tan \left(45 + \frac{\phi}{2} \right) \right)$$

where

$$\alpha = \cos^{-1} \left(1 - \frac{2z}{D} \right)$$

$$t = z \tan^2 (45 - \phi/2)$$

$$K_c = (N_c - \tan \phi) \cos^2 \phi$$

$$K_\gamma = \left(\frac{2N_\gamma}{\tan \phi} + 1 \right) \cos^2 \phi$$

$$\text{and } z = \left[\frac{3W}{(3-m)(Kb)\sqrt{D}} \right]^{\frac{2}{2m+1}}$$

Preliminary calculations show that the last two parts of the equation for R_b can be neglected.

Net Thrust Available, or Drawbar Pull

The difference between the soil thrust and the motion resistance is known as the drawbar pull of the wheel, and must be at least large enough to overcome air resistance and to provide sufficient slope capability.

In environments 1, 2, 4, 6, and 8, the net thrust available from the soil is far in excess of the thrust requirements from air drag and shape considerations.

In environments 5 and 9, the net thrust available is small and exists only at practically zero weight on the wheels. This is satisfactory for 5 but not adequate for the slope conditions in 9. This is illustrated in Figure 13.

In environment 7, the net thrust available is adequate and can be developed with close to 100 per cent weight on the wheels. This is shown in Figure 14.

In environments 5, 7, and 9, the bulldozing resistance is very sensitive to width of the area creating the resistance. It seems improbable that the bulldozing drag of a wheel with an essentially rounded tire will be the same as a flat plate of the same width or a track. It has been assumed that the bulldozing resistance of a wheel is approximately 70 per cent of that of a track of the same nominal width.

Horsepower Requirements To Develop the Given Thrust

These depend primarily on the speed and slip.

$$HP = \frac{\text{Total resistance} \times \text{speed (mph)}}{m \times 375 \times (1 - i_o)}$$

$$\text{now } i_o = \frac{(i_o)}{1} = \frac{(i_o)}{21}$$

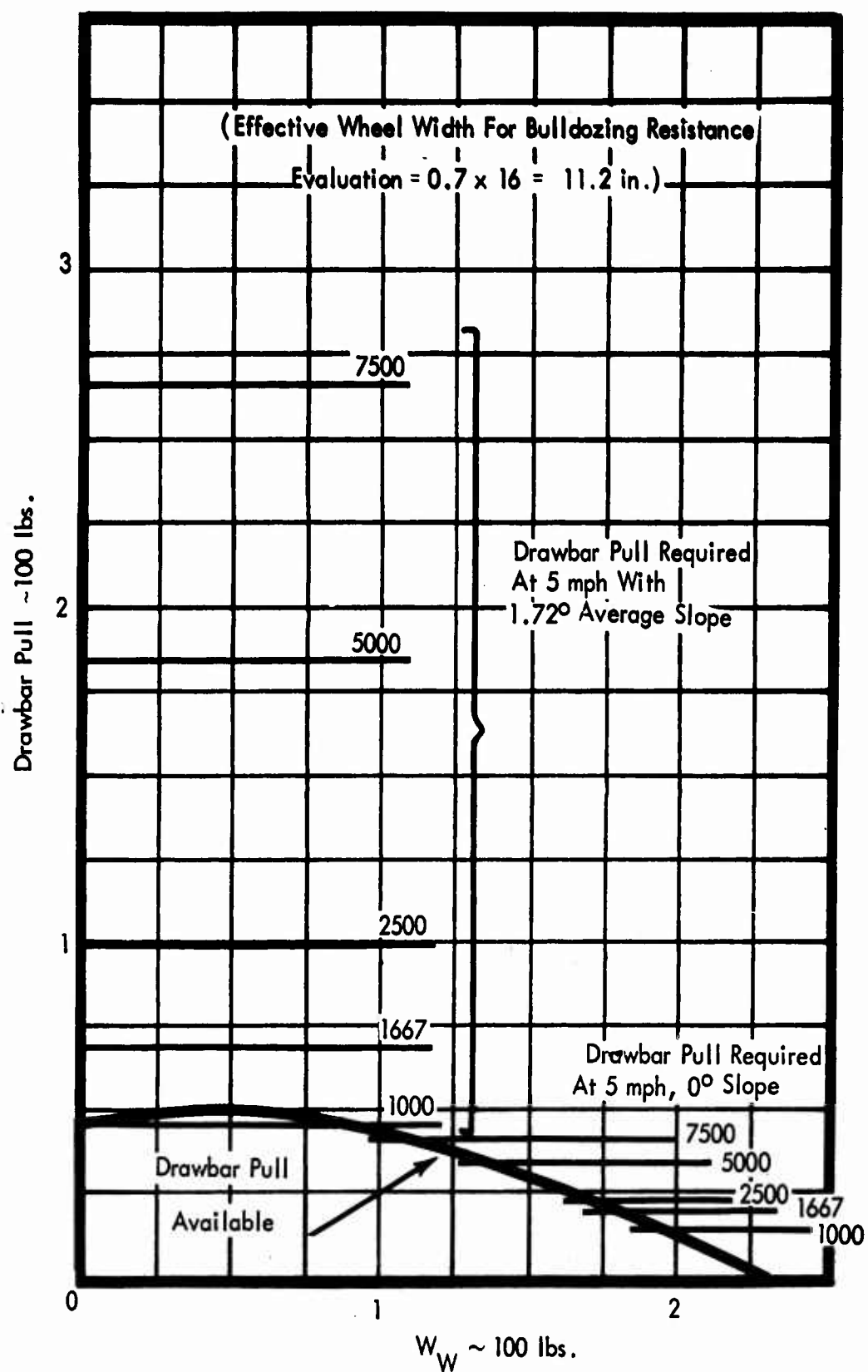


Figure 13. Drawbar Pull Required And Available - Environments 5 and 9

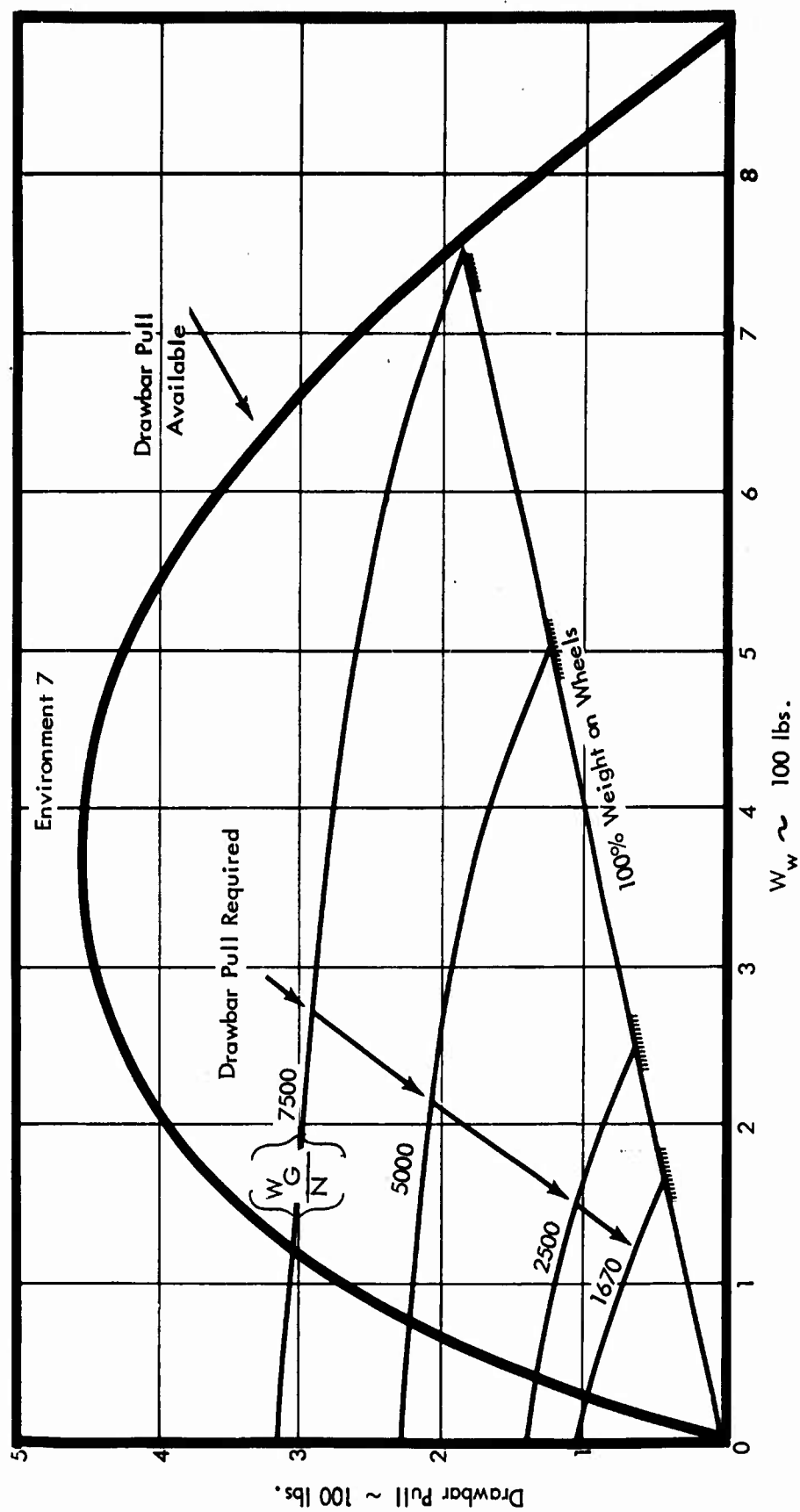


Figure 14. Drawbar Pull Required and Available

For those environments where $\frac{W_w}{(W_G/N)}$ is close to 100 per cent, the required drawbar pull is small, including only aerodynamic drag and tire resistance. Under those conditions, slip is neglected, and

$$\frac{HP}{R_T} = \frac{HP}{T} = \frac{V_{mph}}{m \times 375}$$

For environments 5 and 9, it is assumed that the system is operating at maximum available soil thrust, i.e., at $(i_o \ell)_{opt}$; whereas for environment 7, the thrust required at 100 per cent weight on the wheels will be less than 50 per cent of the maximum available. In this operating range

$$(i_o \ell) = .05 \rightarrow 1.0$$

$$i_o = .024 \rightarrow .048$$

$$(1-i_o) = .976 \rightarrow .952 \div 1.0$$

In environment 5 and 9

$$(i_o \ell) = 5.6$$

$$i_o = .266$$

$$(1-i_o) = .734$$

These are the basic considerations which have determined the values of horsepower per unit thrust, resistance to motion, and weight on the wheels listed under the preceding section on design parameters and again in Table 12. It has been shown that the wheeled ACV's could operate at 100 per cent weight on the wheels in environments 1, 2, 4, 6, and 8. However, in the analysis, consideration of the obstacles in the terrain environment indicated that the vehicles would operate with considerably more weight off the wheels in some of these environments in order to clear the obstacles and to reduce the roughness of the ride in consideration of wear and tear on the vehicle and the payload. This factor is also known to be of great importance where service life of the off-road vehicle must be considerably increased in order to reduce

total costs of the system. Estimates, based on the Landrover Conversion performing in the outback of Australia, indicate normal Landrover service life in addition to greater off-road speeds.

2.5 OPERATIONAL CONSIDERATIONS

Operational considerations will have a significant influence on the development of an optimized off-road air cushion logistics vehicle. These operational considerations include the assumed mission requirements and mission environment, developed in the first chapter, and the payload parameters of size, density, and weight. In order that the optimized vehicle design be responsive to these parameters, they must be quantified in the computer program.

Payload Restraints

The range of vehicle payloads is assumed (Reference 1) as 0 - 5 tons. Within this range of weights, all sizes and densities of military cargoes are considered.

From the payload parameters of weight, density, length, width, and height, the cargo compartment of the vehicle can be sized for most efficient load carrying, and the floor height above the ground and the floor bearing load can be determined. By this method, the capability of the vehicle for handling unitized cargoes can also be established.

Payloads will consist primarily of the five standard classes of military cargoes, with personnel transportation as a secondary capability. Transportation of bulk POL and vehicles will not be considered.

From References 32 and 33, the following composite data on cargo weights and densities can be given, all of which are based on data in Reference 3.

Characteristics of Army Supply Classes

Classes of Supply	Average Density (lb/ft ³)	Consumption in Division Area (lb/day/man)	% of Total Supplied to Division
Class I	23.8	5.8	16
Class II & IV	23.1	4.2	12
Class III (packaged)	33.3	6.0	17
Class V	55.6	19.5	55
TOTAL	42.8	35.5	100

In Reference 34, the optimum cargo compartment size for a given payload weight has been determined on the basis of vehicle functions. It is noted in this study that payload weights associated with 93 per cent of tasks which could be handled by trucks (maximum payload weight 16 tons, maximum payload length 18 feet) were 5 tons or less. This is 93 per cent of the different jobs, not 93 per cent of total tonnage. The requirement for payload space within the payload weight range of 0 - 5 tons, is up to 14-foot length by 8-foot width, although about 90 per cent of the functions could be carried out with a payload compartment length of 12 feet. Payload heights up to 8 feet also need to be considered.

For simplification, the following parameters for the payload compartment of the off-road ACV will be used over the whole range of payload weights.

Payload weight	0-5 tons, (use fixed design for 2-5 tons)
Payload density	20-60 lb/ft ³
Compartment dimensions	length -- 14 feet width -- 8 feet height -- 8 feet (loaded only)

The use of a standard configuration for the payload compartment (with the above parameters) will simplify the development of the optimum vehicle.

It should be noted that provision should be made for transporting missile assemblies and components. For those items in these categories which fall within the weight limitations, length may be a problem; therefore, provision must be made for carrying missile-assembly-type cargoes, in which a portion of the cargo may extend beyond the cargo compartment. Width and height of such assemblies may each be up to 5 feet.

The ability of the standard payload compartment defined above to handle unitized cargo is given below. Within a payload weight of 5 tons and a cargo space of 14 by 8 feet with 8-foot height, the following can be carried:

	2 half-Conex containers	6'3" x 4'3" x 6'10"
or	1 full Conex container	8'6" x 6'3" x 6'10"
or	5 inserts "A"	58" x 33" x 33"
or	6 inserts "B"	45" x 33" x 33"
or	5 pallets	48" x 40" x 53"

In order to meet road overhead clearances (11 feet limiting) while carrying loads up to 8 feet high, a compartment floor height of 3 feet above road surface has been chosen for the initial design analysis (on-road operations only). This can be modified up to 4 feet 6 inches, if too severe (standard Army trucks will not meet 11-foot clearance when loaded with 8-foot items). Cargo compartment floor bearing strength should be based on the heaviest of the anticipated loads (Class V and POL in drums), in which the average floor loading may be up to 150 pounds per square foot.

Mission Requirements

The assumed mission requirements, together with corresponding design and operational parameters, are given in the preceding chapter. The basic mission parameters include payloads of 0 - 5 tons, ranges up to 250 statute miles (payload capacity may be reduced at ranges greater than 100 miles), and a maximum speed requirement (on-road operations) of 40 miles per hour. Off-road mobility and speeds should be optimized to the extent possible, and the vehicles must be air transportable, Phase I. Neglecting environmental considerations at this point, the following mission parameters are included in the model.

1. Speed - need not be greater than 40 miles per hour (from discussion under Section 2.3, this is seen to be nonlimiting).
2. Payload - 0 - 5 tons, as discussed in preceding subsection; range of payloads chosen in Section 2.3.
3. Ranges up to 250 statute miles - payload/range determination will include ranges up to 250 miles, with primary emphasis on ranges of 25 to 100 miles.
4. Vehicle width - 10-foot width considered limiting for road operations. 10-foot width is also minimum cargo compartment width for C-130 aircraft. For required loading clearances (5 inches each side (Reference 6)), maximum width for air transport should not exceed 110 inches (9.17 feet). This modified value will be used in the computer.
5. Vehicle weights - vehicle gross weights selected in Section 2.3 cover range of desired payloads, within reasonable state-of-the-art limits on cushion pressure and planform length-width ratios.

Note: An operations analysis on a specific assumed mission is contained within the chapter entitled Cost/Effectiveness Comparison.

Mission Environment

The assumed mission environment and parameters dependent on environment were included in the previous chapter. The most significant of these were: 30 per cent required gradability, 3-foot ground clearance to hard structure, and limited amphibious capability.

With the available state of the art, it appears that the requirement to negotiate a 30 per cent grade is more demanding in terms of propulsive power than the requirement for high speed. Accordingly, performance of the vehicles within the assumed mission environment will be affected to a greater extent by terrain and route limitations rather than by speed requirements.

Environmental parameters must be determined for the skirted ACV with wheels, as well as the skirted ACV without ground contact. The

assumed mission environment given in Table 1 can be further defined by the use of descriptive terrain parameters. To qualify the assumed mission environment for use in the computer program, each segment of the environment is described by the "significant surface parameters" in the chapter on cost/effectiveness and by an arbitrary average gradient. The average gradient is applied in the design analysis to determine power requirements and fuel flow. While the maximum gradients given in the assumed mission environment segment (Table 1) do determine the maximum power requirement for the vehicle, their use over the entire segment would be unduly conservative. The following average gradients have been selected for the assumed mission environment (computer program only), based on environmental test data and military engineer specifications (References 35 and 36).

		Average Gradient	Maximum Gradient (Table 1)
Segment	1 graded rough road	3%	15%
	2 ungraded open grassland	5%	30%
	3 river crossing	0	banks 30-50%
	4 uncleared forest	0	not given
	5 swamp area	0	0
	6 surfaced highway	0	bank less than 30%
	7 open desert, some dunes	0 for 75% of segment 15% for 25%	dunes to 30%
	8 dry-stream valley	0	not given
	9 rutted muddy road	3%	banks to 30% must be nego- tiated to clear obstacles.

Note that maximum power and traction requirements must be based on the maximum gradients associated with each segment; the average power requirements and fuel consumptions can be based on the average gradients.

Speeds to be used in the computer model will be to a large extent dependent on maneuverability considerations, since only on the steepest slopes will power be limiting. Keeping in mind the maneuvering limitations of the ACV without ground contact, it has been assumed that a clearway will have to be provided through the forest area to allow passage

by skirted ACV's. All other assumed mission environmental segments will be assumed to be negotiable for skirted ACV's with no ground contact, although speeds will be limited in segments 5, 8, and 9 where obstacles must be avoided.

Speeds for the ACV with wheels will be in most cases comparative with conventional wheeled vehicles, except the ACV will be superior (higher speeds) in segments 2, 3, 5, 7, and 9 due to its amphibious capability and ability of clearing small obstacles in open fields, deserts, and rutted muddy roads.

The skirted ACV without ground contact is assumed to use air drive, and the skirted ACV with wheels is assumed to use traction drive (note that its performance in segment 3 (river crossing) is thereby reduced).

The terrain- and route-limited speeds for the skirted ACV and skirted ACV with wheels over the assumed mission environment are given in Table 10. These speeds will be used in the computer program and also in the chapter on cost/effectiveness.

The average speed throughout the entire assumed mission environment is 9.1 miles per hour for the skirted ACV and 11.5 miles per hour for the skirted ACV with wheels. (In this assumed environment comparative speeds for other surface vehicles range from 7.1 to 7.7 miles per hour where limited-to-extensive engineer support is provided. See development in Section 4.3.)

2.6 COMPUTER ANALYSIS

The "off-road" deterministic model was programmed for the CDC 160 computer. Tables 11 and 12 show the input data for the basic configuration, the pure ACV, and the wheeled ACV. Data in these tables are separated into two segments, the top part being used to size the vehicle initially and the bottom part being used in determination of the performance. It should be noted that the program is capable of accommodating variations in all the parameters listed, although the analysis includes only the variation previously indicated.

The results are tabulated systematically by the computer in a form as shown by Tables 13, 14, 15, and 16. The weight of fuel used in each segment is tabulated and summed at the bottom of the outbound and inbound segments. The payload carried during the maneuver is

TABLE 10
ACV OPERATING SPEEDS IN ASSUMED
MISSION ENVIRONMENT

Route Segment	Percen- tages of Total Mileage	Average Skirted ACV Speeds (mph)	
		No Wheels	With Wheels
1. Graded rough road with gradients less than 15 per cent	15	15	20
2. Ungraded open grassland, obstacles less than 3 feet, rolling grades less than 30 per cent	20	12	15
3. River crossing, banks 30-50 per cent, current 3 knots	5	25	10 (can be in- creased with water prop.)
4. Uncleared Forest, trees spaced 15-30 feet, undergrowth to 2 feet, occasional stumps up to 3 feet	10	clearing req'd 5	5
5. Swamp area, scattered vegetation, only occasional obstacles over 2 feet, space between tree roots over 15 feet	10	marginal 4	5
6. Two-lane surfaced highway, soft shoulders, bank less than 30 per cent	25	20	30 +
7. Open desert with some dunes, gradients on dunes up to 30 per cent	5	15	15
8. Dry-stream valley, twisting floor bed with rocks up to 2 feet, rocky banks	5	(5)	5
9. Rain-soaked, graded dirt road, wheel ruts up to 2 feet deep, obstacles require periodic leaving road and returning up and down grades 30 per cent	5	5	5
	100		

TABLE 11
DATA INPUT FOR OFF-ROAD DETERMINISTIC MODEL
PURE ACV

Configuration 6				Run 22			
Vehicle sizing parameters:							
W_G	= 20,000 lb	w_v	= 9.17	γ	= 16.7 deg.		
W_E	= 1,000 lb	h_e	= .5	q/p_c	= 1		
W_s/s	= 20 lb/ft ²	η_D	= .8	B	= .05 h_e		
p_c	= 90 lb/ft ²	η_I	= .9	$\frac{W_L}{HP_L}$	= 1.7 lb/hp (2.2 for recip. engines)		
A	= .87	η_m	= .85				
W_W	= .00 W_{G_n}	x	= .85	V	= 40 mph		
		θ	= .55 deg.	$\frac{HP_P}{T}$	= .25 hp/lb		
				$\frac{W_P}{HP_P}$	= 1.7 lb/hp (2.2 for recip. engines)		
Vehicle range equation parameters:							
Range (one way) 50 s. mi.				Total range 100 s. mi.			
Segment	V_n	$(\Delta R/R)_n$	$SFC^*_{L_n}$	$SFC^*_{P_n}$	$(HP/T)_n$	$(HP/T)_n$	γ_n
	mph		lb/hr/hp	lb/hr/hp	hp/lb	hp/lb	deg.
1	15	.15	.7	.7	.25	.25	1.72
2	12	.20	.7	.7	.25	.25	2.86
3	25	.05	.7	.7	.25	.25	0
4	5	.10	.7	.7	.25	.25	0
5	4	.10	.7	.7	.25	.25	0
6	20	.25	.7	.7	.25	.25	0
7	15	.05	.7	.7	.25	.25	0- 5.74
8	5	.05	.7	.7	.25	.25	0
9	5	.05	.7	.7	.25	.25	1.72
* For reciprocating engines, SFC = .4							

TABLE 13
TYPICAL DATA OUTPUT FROM OFF-ROAD DETERMINISTIC MODEL
PURE ACV WITH TURBINE ENGINES

RUN 22									
sv =	.25542e 03	c =	.69068e 02	hpl =	.98692e 03	rqv =	.55065e 03	tr =	.57190e 04
wp =	.24305e 04	wl =	.16777e 04	ws =	.51085e 04	plf =	.48915e 00	s =	.22222e 03
								lv =	.27854e 02
RR	WGN	PCN	HPLN	HPPN	EXP	WF			
.75000e 01	.20000e 05	.90000e 02	.98692e 03	.20160e 03	-.20799e-01	.41168e 03			
.10000e 02	.19588e 05	.88147e 02	.95660e 03	.28562e 03	-.36993e-01	.71139e 03			
.25000e 01	.18876e 05	.84946e 02	.90496e 03	.83588e 02	-.36658e-02	.69071e 02			
.50000e 01	.18807e 05	.84635e 02	.90000e 03	.16687e 02	-.34117e-01	.63086e 03			
.50000e 01	.18176e 05	.81796e 02	.85510e 03	.13123e 02	-.41794e-01	.74404e 03			
.12500e 02	.17432e 05	.78448e 02	.80314e 03	.64262e 02	-.21768e-01	.37538e 03			
.25000e 01	.17057e 05	.76758e 02	.77734e 03	.15410e 03	-.63707e-02	.10832e 03			
.25000e 01	.16949e 05	.76271e 02	.76994e 03	.15841e 02	-.16226e-01	.27280e 03			
.25000e 01	.16676e 05	.75043e 02	.75143e 03	.14076e 03	-.18725e-01	.30936e 03			
vgf =	.16367e 05	wff =	.36329e 04						
.75000e 01	.10216e 05	.45976e 02	.36034e 03	.11351e 03	-.16232e-01	.16451e 03			
.10000e 02	.10381e 05	.46716e 02	.36908e 03	.15946e 03	-.29699e-01	.30378e 03			
.25000e 01	.10685e 05	.48083e 02	.38540e 03	.62888e 02	-.29367e-02	.31334e 02			
.50000e 01	.10716e 05	.48224e 02	.38709e 03	.12596e 02	-.26107e-01	.27616e 03			
.50000e 01	.10992e 05	.49467e 02	.40215e 03	.10205e 02	-.32823e-01	.35495e 03			
.12500e 02	.11347e 05	.51064e 02	.42179e 03	.51847e 02	-.18260e-01	.20533e 03			
.25000e 01	.11553e 05	.51988e 02	.43329e 03	.11132e 03	-.54997e-02	.63363e 02			
.25000e 01	.11616e 05	.52273e 02	.43686e 03	.13114e 02	-.13557e-01	.15642e 03			
.25000e 01	.11722e 05	.52977e 02	.44571e 03	.10148e 03	-.16267e-01	.18996e 03			
vgf1 =	.11962e 05	wpl =	.44042e 04	wff1 =	.17458e 04				

TABLE 14
TYPICAL DATA OUTPUT FROM OFF-ROAD DETERMINISTIC MODEL
PURE ACV WITH RECIPROCATING ENGINES

RUN 34									
sv =	.25542e 03	c =	.69068e 02	hpl =	.98692e 03	rqv =	.55065e 03	tr =	.57190e 04
vp =	.31454e 04	wl =	.21712e 04	ws =	.51085e 04	plf =	.42873e 00	s =	.22222e 03
								lv =	.27854e 02
RR	WGN	PCN	HPLN	HPPN	EXP	WF			
.75000e 01	.20000e 05	.90000e 02	.98692e 03	.20160e 03	-.11885e-01	.23629e 03			
.10000e 02	.19763e 05	.88936e 02	.96948e 03	.28799e 03	-.21208e-01	.41474e 03			
.25000e 01	.19348e 05	.87070e 02	.93912e 03	.84627e 02	-.21163e-02	.40906e 02			
.50000e 01	.19308e 05	.86886e 02	.93614e 03	.16907e 02	-.19744e-01	.37748e 03			
.50000e 01	.18930e 05	.85187e 02	.90882e 03	.13393e 02	-.24358e-01	.45554e 03			
.12500e 02	.18475e 05	.83137e 02	.87622e 03	.66155e 02	-.12752e-01	.23409e 03			
.25000e 01	.18240e 05	.82084e 02	.85962e 03	.16311e 03	-.37378e-02	.68055e 02			
.25000e 01	.18172e 05	.81777e 02	.85481e 03	.16402e 02	-.95881e-02	.17341e 03			
.25000e 01	.17999e 05	.80997e 02	.84260e 03	.15130e 03	-.11043e-01	.19768e 03			
vgf =	.17801e 05	wff =	.21982e 04						
.75000e 01	.11425e 05	.51413e 02	.42612e 03	.12469e 03	-.96421e-02	.10963e 03			
.10000e 02	.11534e 05	.51907e 02	.43227e 03	.17548e 03	-.17563e-01	.20081e 03			
.25000e 01	.11735e 05	.52810e 02	.44360e 03	.65907e 02	-.17366e-02	.20362e 02			
.50000e 01	.11756e 05	.52902e 02	.44476e 03	.13192e 02	-.15581e-01	.18176e 03			
.50000e 01	.11937e 05	.53720e 02	.45511e 03	.10635e 02	-.19507e-01	.23062e 03			
.12500e 02	.12168e 05	.54758e 02	.46837e 03	.53689e 02	-.10725e-01	.12981e 03			
.25000e 01	.12298e 05	.55342e 02	.47588e 03	.1 721e 03	-.32151e-02	.39476e 02			
.25000e 01	.12337e 05	.55519e 02	.47817e 03	.13515e 02	-.79705e-02	.97949e 02			
.25000e 01	.12435e 05	.55960e 02	.48388e 03	.10682e 03	-.95001e-02	.11758e 03			
vgf1 =	.12553e 05	wpl =	.52484e 04	wff1 =	.11280e 04				

TABLE 15
TYPICAL DATA OUTPUT FROM OFF-ROAD DETERMINISTIC MODEL
WHEELED ACV WITH TURBINE ENGINES

RR	WGN	PCN	HPLN	HPPN	EXP	WF
RUN 80						
sv = .28860e 03	c = .71326e 02	hpl = .10191e 04	rqv = .56855e 03	tr = .57190e 04		
vp = .29167e 03	wl = .17326e 04	ws = .57720e 04	plf = .46018e 00	s = .22222e 03	lv = .31472e 02	
.75000e 01	.20000e 05	.00000e-32	.00000e-32	.62994e 02	-.82680e-03	.16528e 02
.10000e 02	.19983e 05	.44962e 02	.35989e 03	.63417e 02	-.98853e-02	.19657e 03
.25000e 01	.19786e 05	.89041e 02	.10029e 04	.43835e 01	-.89090e-02	.17549e 03
.50000e 01	.19611e 05	.44125e 02	.34988e 03	.39341e 01	-.12629e-01	.24611e 03
.50000e 01	.19365e 05	.82786e 02	.89914e 03	.11730e 02	-.16462e-01	.31619e 03
.12500e 02	.19049e 05	.00000e-32	.00000e-32	.35812e 02	-.54833e-03	.10442e 02
.25000e 01	.19038e 05	.17134e 02	.84665e 02	.45799e 03	-.33253e-02	.63205e 02
.25000e 01	.18975e 05	.42694e 02	.33300e 03	.38193e 01	-.62126e-02	.11752e 03
.25000e 01	.18857e 05	.80617e 02	.86404e 03	.21716e 02	-.16439e-01	.30747e 03
wgf = .18550e 05	wff = .14495e 04					
.75000e 01	.10796e 05	.00000e-32	.00000e-32	.34005e 02	-.82680e-03	.89222e 01
.10000e 02	.10805e 05	.24311e 02	.14309e 03	.35669e 02	-.77204e-02	.83100e 02
.25000e 01	.10888e 05	.48997e 02	.40940e 03	.32517e 01	-.66322e-02	.71975e 02
.50000e 01	.10960e 05	.24660e 02	.14618e 03	.23489e 01	-.94862e-02	.10348e 03
.50000e 01	.11063e 05	.47297e 02	.38828e 03	.74820e 01	-.12519e-01	.13765e 03
.12500e 02	.11201e 05	.00000e-32	.00000e-32	.21058e 02	-.54833e-03	.61406e 01
.25000e 01	.11207e 05	.10086e 02	.38240e 02	.27065e 03	-.32155e-02	.35980e 02
.25000e 01	.11243e 05	.25297e 02	.15188e 03	.24019e 01	-.48028e-02	.53870e 02
.25000e 01	.11297e 05	.48296e 02	.40064e 03	.13304e 02	-.12824e-01	.14395e 03
wgfi = .11441e 05	wpl = .71090e 04	wfri = .64508e 03				

TABLE 16 TYPICAL DATA OUTPUT FROM OFF-ROAD DETERMINISTIC MODEL WHEELED ACV WITH RECIPROCATING ENGINES									
RUN 86	sv = .28860e 03	c = .71326e 02	hpl = .10191e 04	rqv = .56865e 03	tr = .57190e 04				
	vp = .37745e 03	wl = .22422e 04	ws = .57720e 04	plf = .43041e 00	s = .22222e 03	lv = .31472e 02			
RR	WGN	PCN	HPLN	HPPN	EXP	WF			
.75000e 01	.20000e 05	.00000e-32	.00000e-32	.62994e 02	-.47245e-03	.94476e 01			
.10000e 02	.19990e 05	.44978e 02	.36008e 03	.63439e 02	-.56496e-02	.11262e 03			
.25000e 01	.19877e 05	.89450e 02	.10098e 04	.43935e 01	-.51024e-02	.10116e 03			
.50000e 01	.19776e 05	.44497e 02	.35432e 03	.39639e 01	-.72465e-02	.14279e 03			
.50000e 01	.19633e 05	.83935e 02	.91792e 03	.11864e 02	-.94712e-02	.18507e 03			
.12500e 02	.19448e 05	.00000e-32	.00000e-32	.36563e 02	-.31333e-03	.60913e 01			
.25000e 01	.19442e 05	.17498e 02	.87375e 02	.46765e 03	-.19031e-02	.36966e 02			
.25000e 01	.19405e 05	.43663e 02	.34439e 03	.38970e 01	-.35896e-02	.69533e 02			
.25000e 01	.19336e 05	.82662e 02	.89712e 03	.22245e 02	-.95092e-02	.18300e 03			
wgf = .19153e 05	wff = .84670e 03								
.75000e 01	.11391e 05	.00000e-32	.00000e-32	.35880e 02	-.47245e-03	.53811e 01			
.10000e 02	.11397e 05	.25643e 02	.15500e 03	.37478e 02	-.45037e-02	.51214e 02			
.25000e 01	.11448e 05	.51517e 02	.44138e 03	.33342e 01	-.38846e-02	.44385e 02			
.50000e 01	.11492e 05	.25858e 02	.15696e 03	.24484e 01	-.55482e-02	.63586e 02			
.50000e 01	.11556e 05	.49402e 02	.41449e 03	.77431e 01	-.73075e-02	.84139e 02			
.12500e 02	.11640e 05	.00000e-32	.00000e-32	.21883e 02	-.31333e-03	.36457e 01			
.25000e 01	.11644e 05	.10479e 02	.40495e 02	.28111e 03	-.18413e-02	.21420e 02			
.25000e 01	.11665e 05	.26247e 02	.16051e 03	.24806e 01	-.27945e-02	.32553e 02			
.25000e 01	.11697e 05	.50008e 02	.42214e 03	.13752e 02	-.74525e-02	.86855e 02			
wgf1 = .11784e 05	wpl = .73684e 04	wff1 = .39318e 03							

shown at the bottom line. Definition of all symbols used in the program follows:

A	ratio of cushion area to vehicle planform area
B	per cent of lift horsepower required for stability
EXP	power of the exponent, e , for each environmental segment, n
HPLN	lift horsepower required for each environmental segment, n
HPPN	propulsion horsepower regained for each environmental segment, n
HP_P/T	horsepower required per unit thrust of propelling force
$(HP/T)_n$	horsepower required per unit thrust of propelling force in a particular environmental segment, n , of the out-bound leg (loaded)
K_1	resistance of the wheeled system as a function of the weight on the wheels
$(HP/T)_n$	horsepower required per unit thrust of propelling force in a particular environmental segment, n , of the in-bound leg (empty)
PCN	cushion pressure in each environmental segment, n
RR	range in each environmental segment, n
$(\Delta R/\frac{R}{2})_n$	the per cent of range in each environmental segment, n , for both outbound and inbound legs
SFC_{L_n}	lift engine specific fuel consumption for each environmental segment, n
SFC_{P_n}	propulsion engine specific fuel consumption for each environmental segment, n

V	maximum design forward velocity of the vehicle
V_n	forward velocity of the vehicle in each range segment, n
W_E	weight of equipment (including wheels and suspension system for the wheeled ACV)
W_G	initial gross weight of the vehicle
WF	weight of fuel
WGN	gross weight of the vehicle in each outbound environmental segment, n
W_L/HP_L	weight of lift engines per unit horsepower
W_P/HP_P	weight of propelling engines per unit horsepower
W_S/S	weight of structure per unit cushion planform area
c	perimeter of the annular jet (measured at center line of jet)
h_e	effective height of the air curtain
hpl	maximum lift horsepower required
l_v	length of the vehicle
plf	payload and fuel in per cent of gross weight
q/p_c	speed parameter
rqv	maximum momentum drag
s	cushion planform area
sv	vehicle planform area

tr	propelling thrust required
wff	weight of fuel used on outbound leg
$wffi$	weight of fuel used on inbound leg
wgf	gross weight of vehicle after outbound leg completed
$wgfi$	gross weight of vehicle before inbound leg started
wl	weight of lift system
wp	weight of propelling system
wpl	weight of payload
ws	weight of structure
w_v	maximum vehicle width
x	jet thickness parameter
γ	maximum angle of grade which must be traversed
γ_n	average grade angle negotiated in each environmental segment, n
η_D	lift system ducting efficiency
η_I	engine intake efficiency
η_m	mechanical drive efficiency
θ	deflection angle of annular jet measured from the vertical.

2.7 RESULTS OF ANALYSIS

The capability of the BAARINC "off-road" deterministic model to accommodate changes over a large range of variables (up to 83) has the advantages that many different aspects of the vehicle design can be explored. An associated disadvantage, however, becomes apparent, since such a large number of effects can overwhelm the reader with sheer volume. It was therefore decided to strike a happy medium and to use as constants most of the parameters which determine vehicle size while investigating the significance of varying the parameters in the performance computations. The former have been investigated in many other sources and typical values have been chosen. The latter are main items which significantly affect the choice of a vehicle for the economic analysis, or are items which have not been evaluated in a consistent manner in previous material.

All the variations were evaluated about some fixed configuration and range which was used as nominal for the economic analysis. A 20,000-pound gross weight was chosen for a total range of 100 statute miles for both the pure ACV and the wheeled ACV. The design inputs and results are as shown in the previous section. Figure 15 presents the effect of range on the payload-carrying capability of both types of machines for different assumed gross weights. It shows that the larger the vehicle, the more payload it can carry, even though it uses more fuel. It also shows the gain associated with equipping the vehicle with wheels. As would be expected, the wheeled vehicles are not as good for very short range, because of the additional weight of the wheels. But, as the use of wheels reduces the amount of weight which the lift system must support during operations and since the lift system is the prime user of fuel, much can be gained for long ranges. In fact, the pure ACV has no capability at ranges as great as 250 miles, while the wheeled ACV can carry considerable payload for this distance.

The effect of gross weight on payload is more vividly expressed in Figure 16. Notice that at zero range, the capabilities of each vehicle are quite similar. At 100 miles, however, the capabilities are divergent, with the heavier wheeled vehicles providing a greater and greater payload ratio as the gross weight of the vehicle increases.

In these calculations, an equipment weight of 3,000 pounds was used for the wheeled ACV, which included 2,000 pounds for the suspension system. Figure 17 shows that the effect of varying this suspension

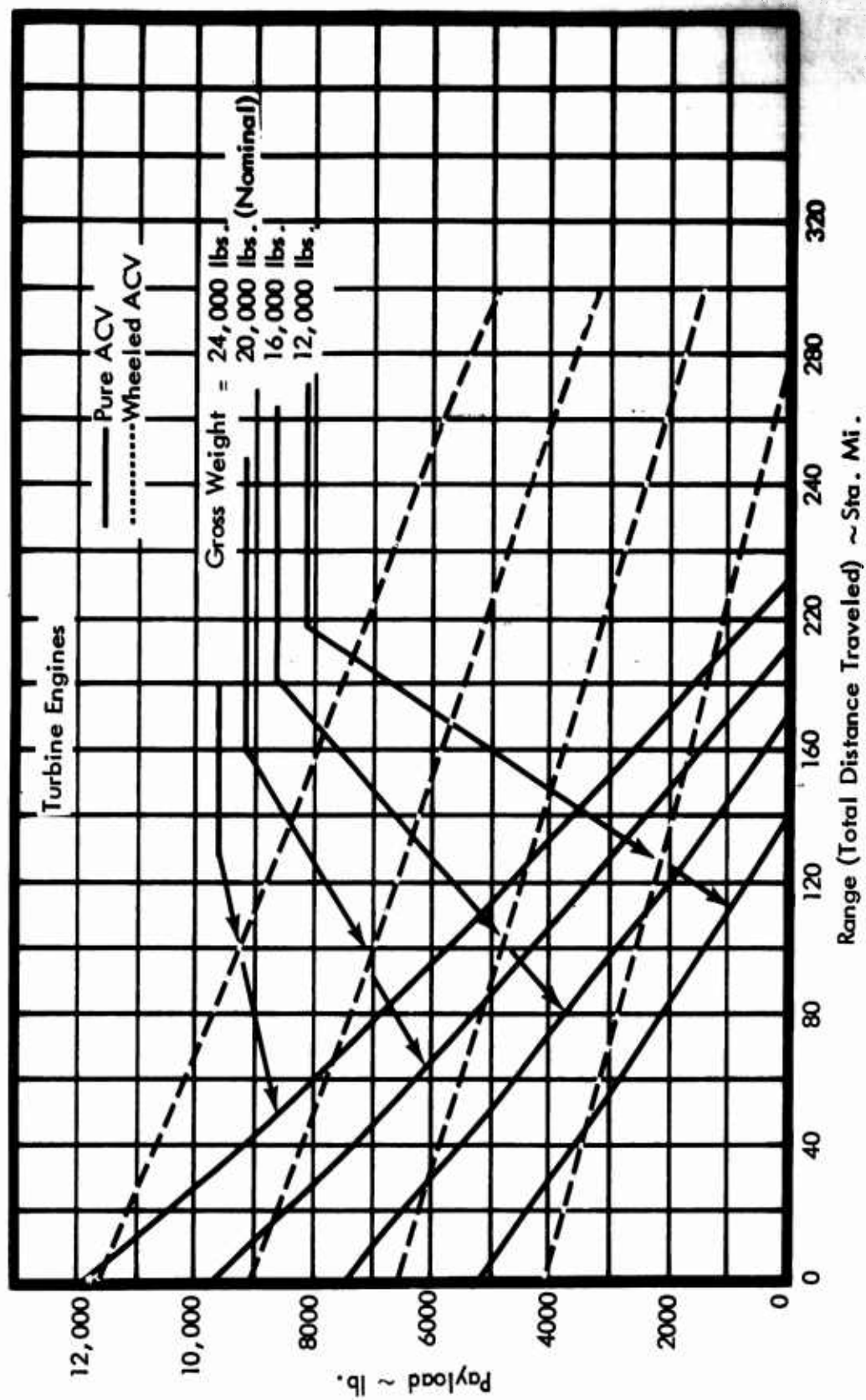
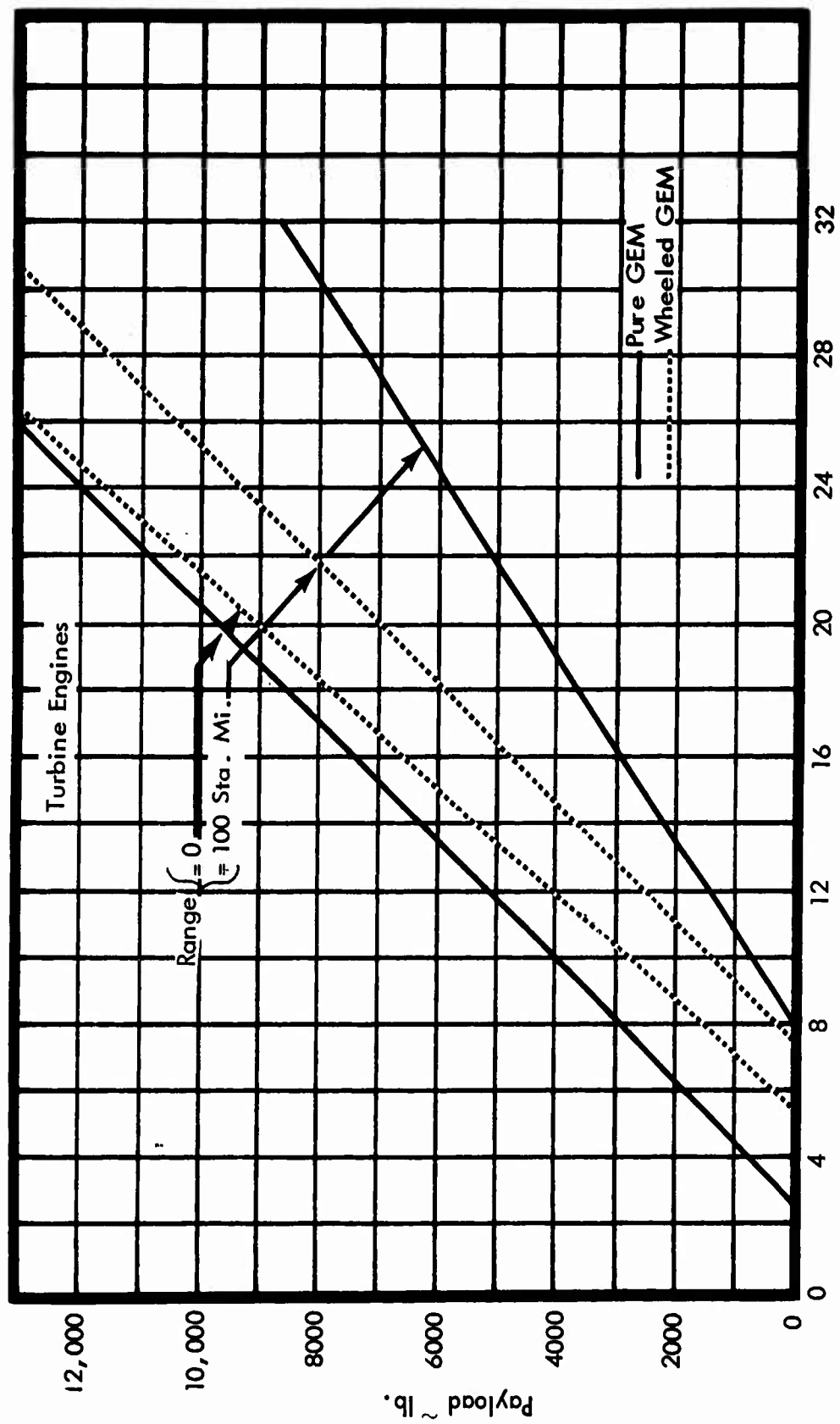


Figure 15. Payload Range Comparison



Vehicle Gross Weight ~ 1000 lb.

Figure 16. Payload Capability

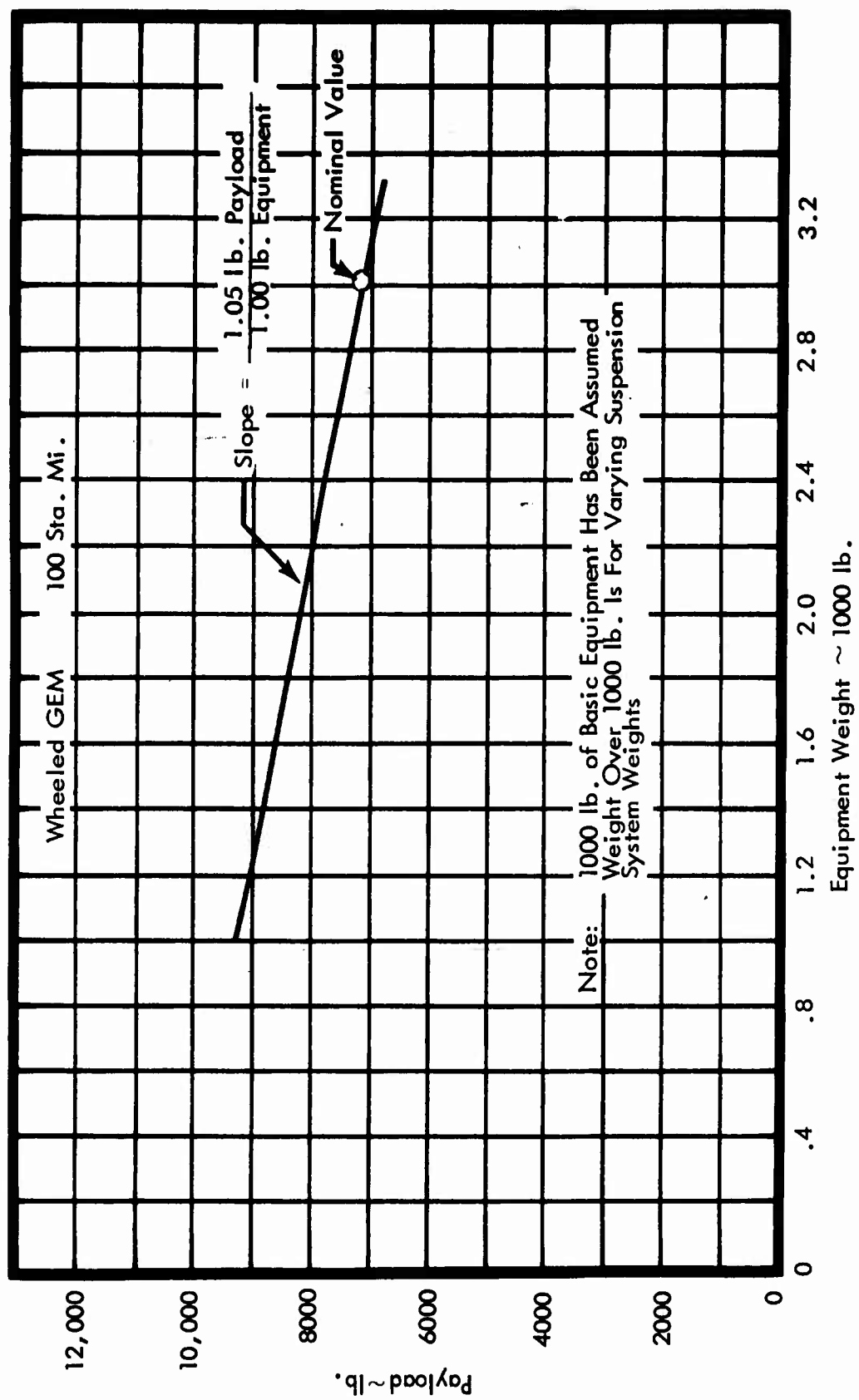


Figure 17. Effect of Varying Equipment Weight

system is almost directly proportional to the payload for the 100-mile range. Reduction of this system weight would have an important but not overwhelming effect.

One of the outputs of the model is vehicle length. The cushion area to planform area were chosen as constants, being .88 for the pure ACV and .77 for the wheeled ACV to accommodate the wheels outside of the skirt. Figure 18 shows the effects of vehicle gross weight on length and indicates the major consideration for choosing a 20,000-pound vehicle as the prime carrier for the economic analysis. With the width held constant at 9.17 feet for transportability considerations, the 20,000-pound pure ACV has a three-to-one length to width ratio, a value approaching the maximum for stability considerations for the pure ACV. For the wheeled ACV, such a gross weight requires a vehicle 31.5 feet long -- a value approaching the maximum when considering terrain and environment maneuvering limitations. As we have seen from previous figures, it would be of value to go to higher gross weights for pure load-carrying capability, but the 20,000-pound vehicle represents a compromise for these other considerations. In any event, both vehicles should have more than adequate capability to meet the required payload compartment size. This is an inherent feature of the ACV, for most will have more than adequate payload area available for the weights carried.

As mentioned earlier, the propulsion system represents one of the major weight items. Figures 19 and 20 show results of specific changes. In Figure 19, the specific fuel consumption is varied from .8 to .5 pound per horsepower hour. Previous data indicated that .7 is a typical value, but some sources are quoting numbers as low as .5 for turbine engines. This latter number may be typical for larger engines; but in this case, significant amounts of available power will not be used during normal operation, and the propulsion system must be made up of a number of smaller units for the most efficient operation, a condition which will tend to increase the values of specific fuel consumption. In any event, the pure ACV is affected to a greater degree than the wheeled ACV, since it uses more fuel as a result of carrying the full weight of the vehicle at all times. The same type of situation is presented in Figure 20 when considering the specific weight of the engines. Earlier in this chapter, specific weight was analyzed, and it was concluded that turbine propulsion systems would nominally weigh 1.7 pounds per horsepower while reciprocating propulsion systems would weigh 2.2 pounds per horsepower. This

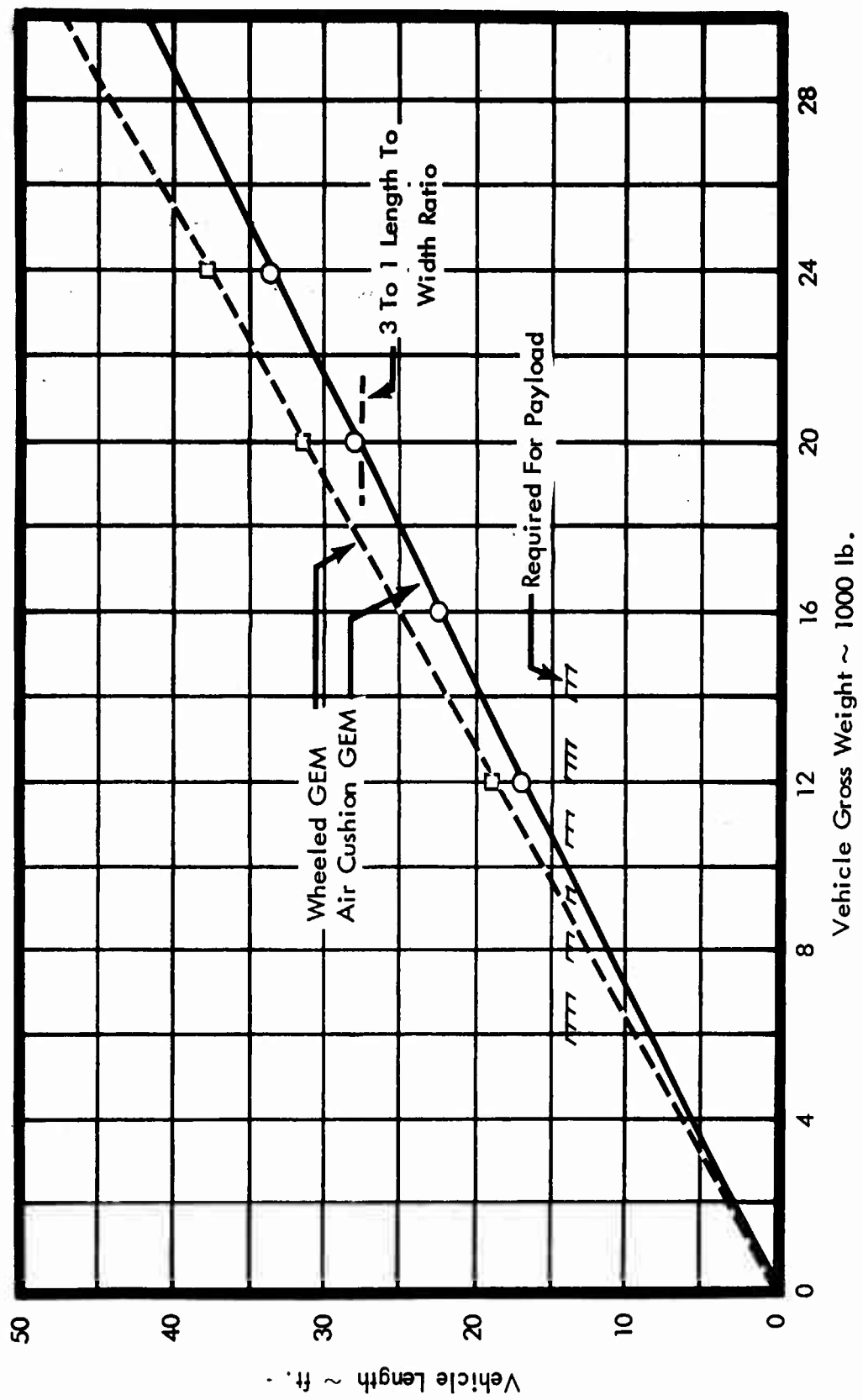


Figure 18. Vehicle Lengths

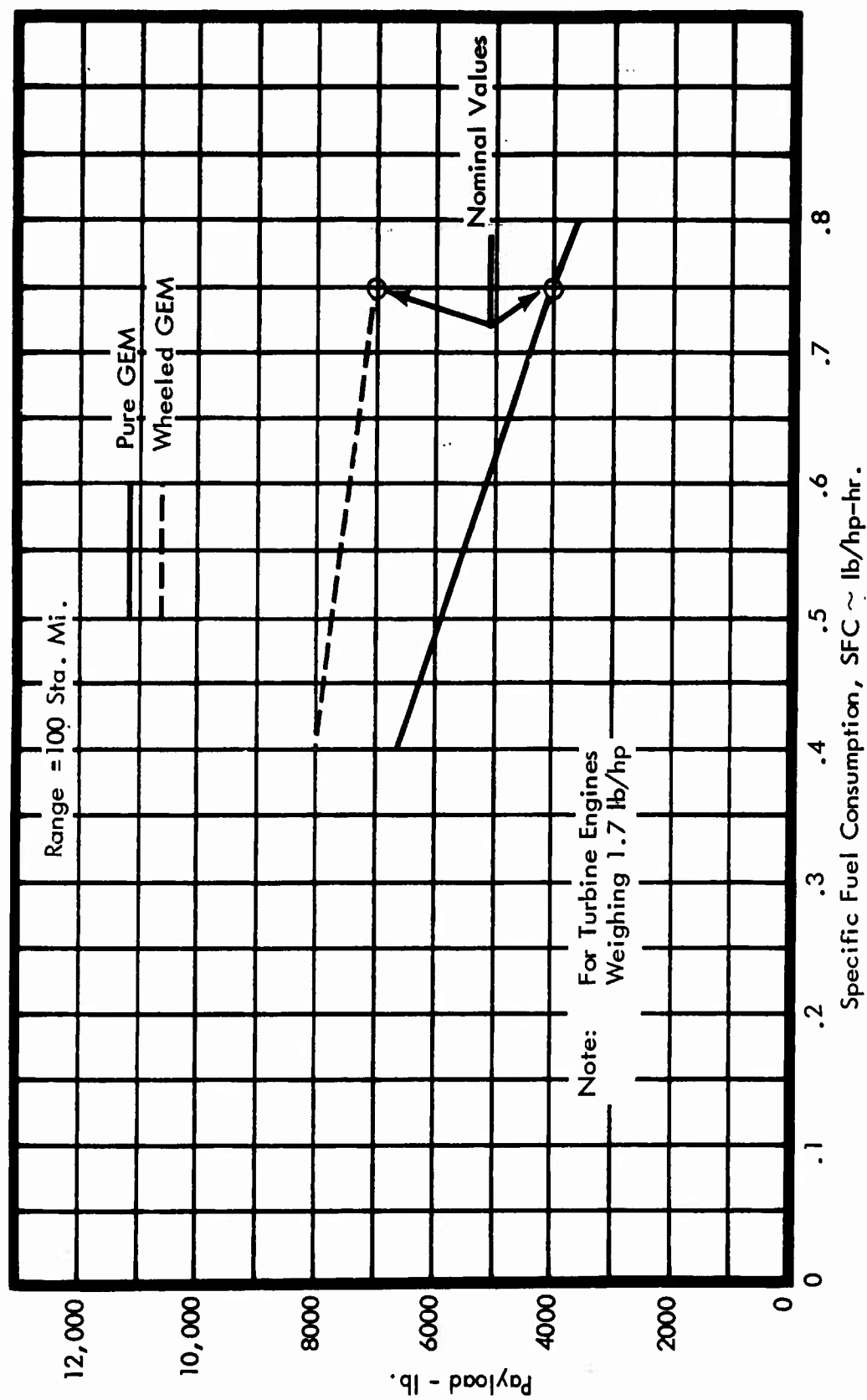
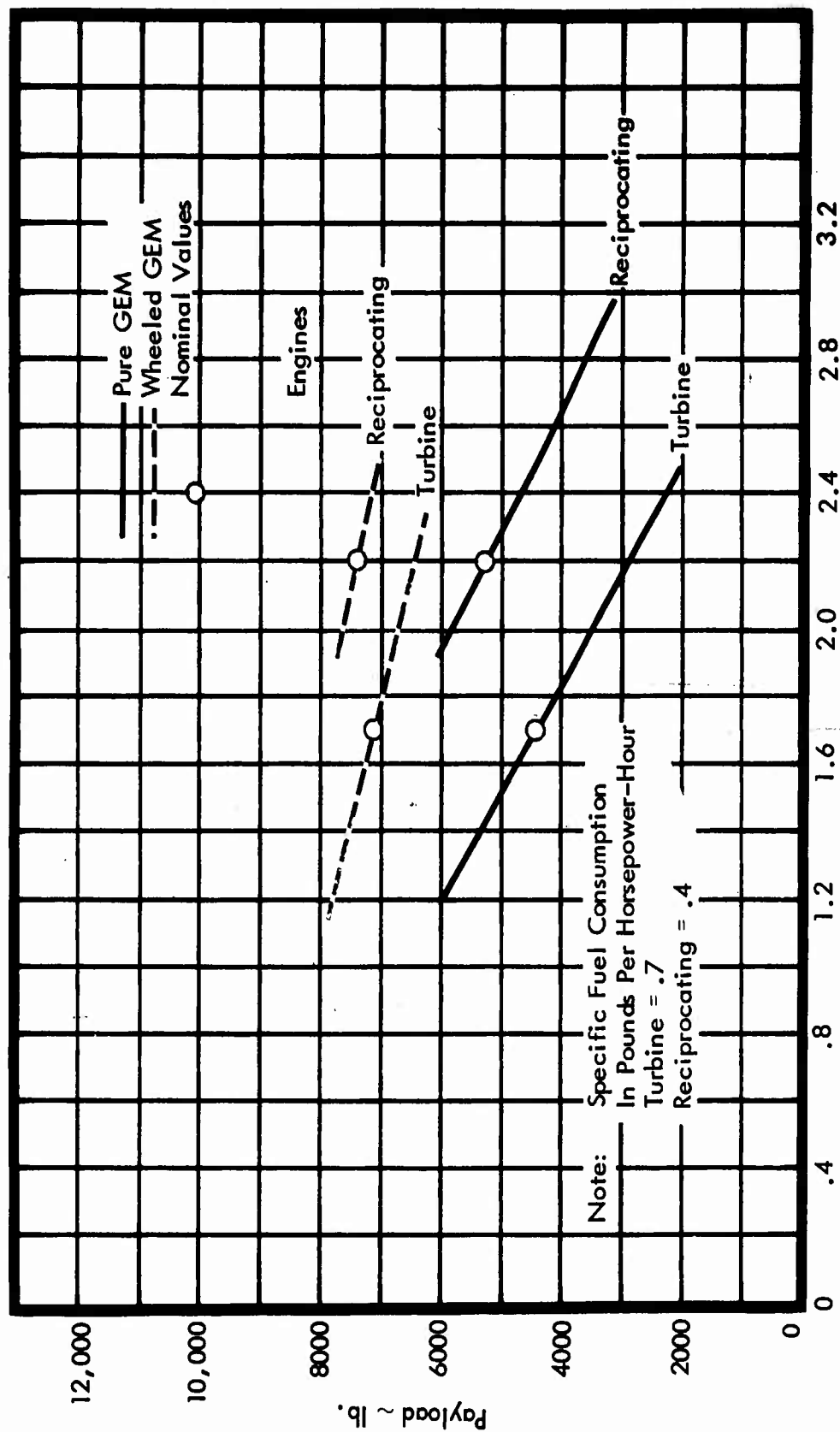


Figure 19. Effect Of Specific Fuel Consumption



Specific Weight Of Propulsion System ~ lb/hp.

Figure 20. Effect Of Propulsion System Specific Weight

curve shows the reciprocating system to some advantage: 850 pounds of payload for the pure ACV and 250 pounds for the wheeled ACV over a 100-mile range. Reference 16, however, uses specific weights of 1.4 and 2.5 for the turbine and reciprocating systems respectively, which, from Figure 20, would show the turbine system to be of greater advantage.

The comparison of systems as shown in Figure 21 clearly illustrates the results. A diesel engine was included for comparative purposes, and, as expected, was shown to be undesirable because of its very high specific weight. The wheeled vehicle is clearly superior while reciprocating engine systems are marginally better from a payload-carrying standpoint for ranges of 100 miles.

An area of some uncertainty, tractive effect, was evaluated and the results presented in Figures 22 and 23. In Figure 22, variations from the basic assumption of .25 horsepower per pound of thrust for a propeller-driven pure ACV are shown. The value of .25 was assumed as nominal for a shrouded propeller designed for low-speed operation, and tractive effect does not seem to have a very large effect on performance. In this case, the increased tractive effect was assumed to apply in the vehicle sizing situation as well as in the actual performance relationships. Figure 23, however, merely shows the effect of changing the value of tractive effect from the nominal value of .03 in the vehicle sizing portion of the analysis, since specific values dependent on the environment must be used in the performance analysis of the wheeled ACV. In either case, tractive effect does not appear to be a very significant effect.

Mission profiles for the two selected 20,000-pound vehicles are shown in Figure 24. The changing slopes of the lines for the pure ACV show the effect of velocity and grades encountered in the environment. For the wheeled ACV, additional factors taken into account are weight on the wheels; tractive effect required; and deflection, compaction, and bulldozing resistance due to the wheels.

These effects are dramatized in Figure 25. These slopes can be used for a first-order approximation of the effect of changing the environments from the standard environment. For instance, suppose it is desired to determine the fuel used for a total mission length of 75 miles on a pioneer road. The rate of fuel consumption for this type

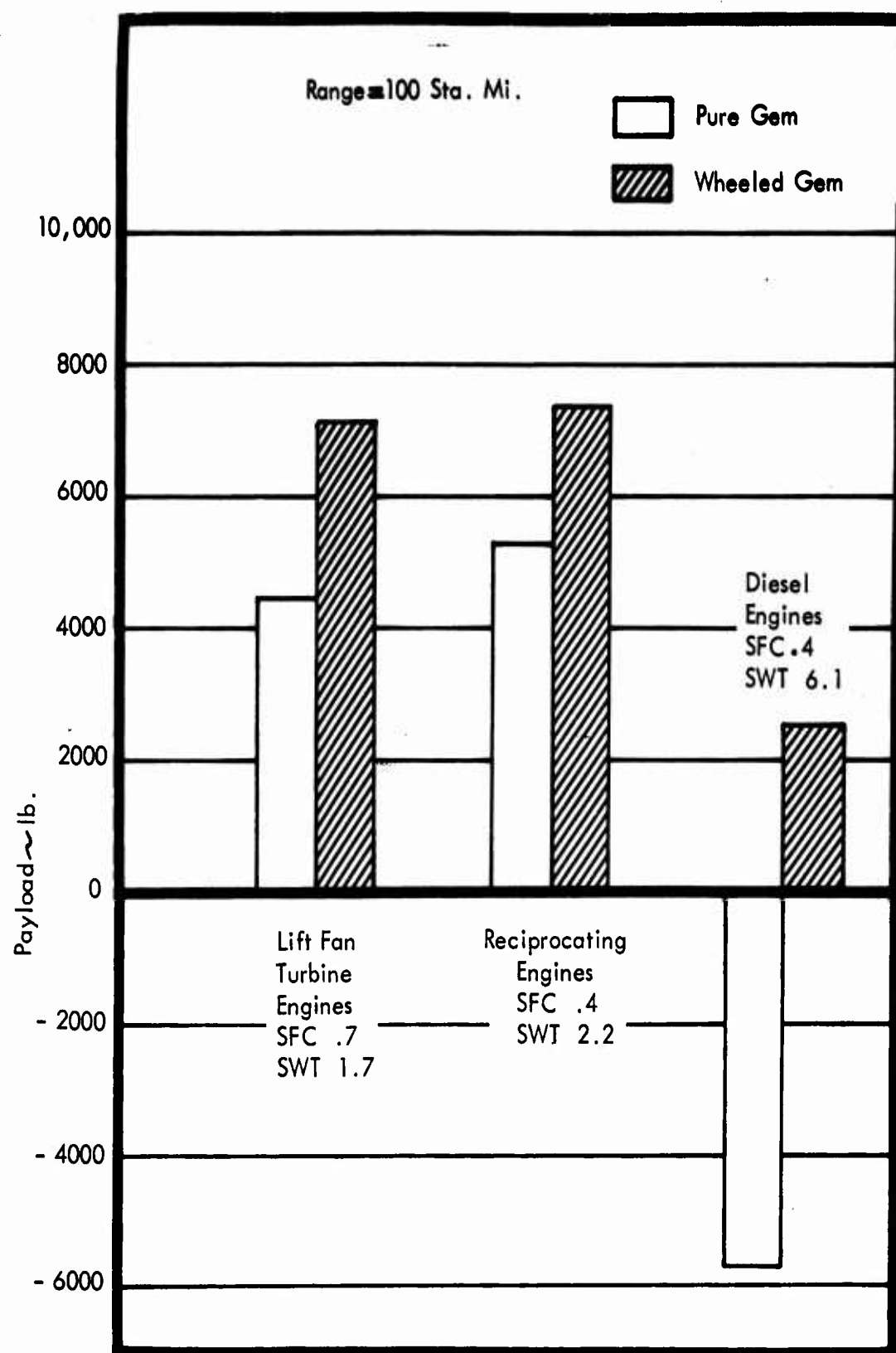


Figure 21 Propulsion System Comparison

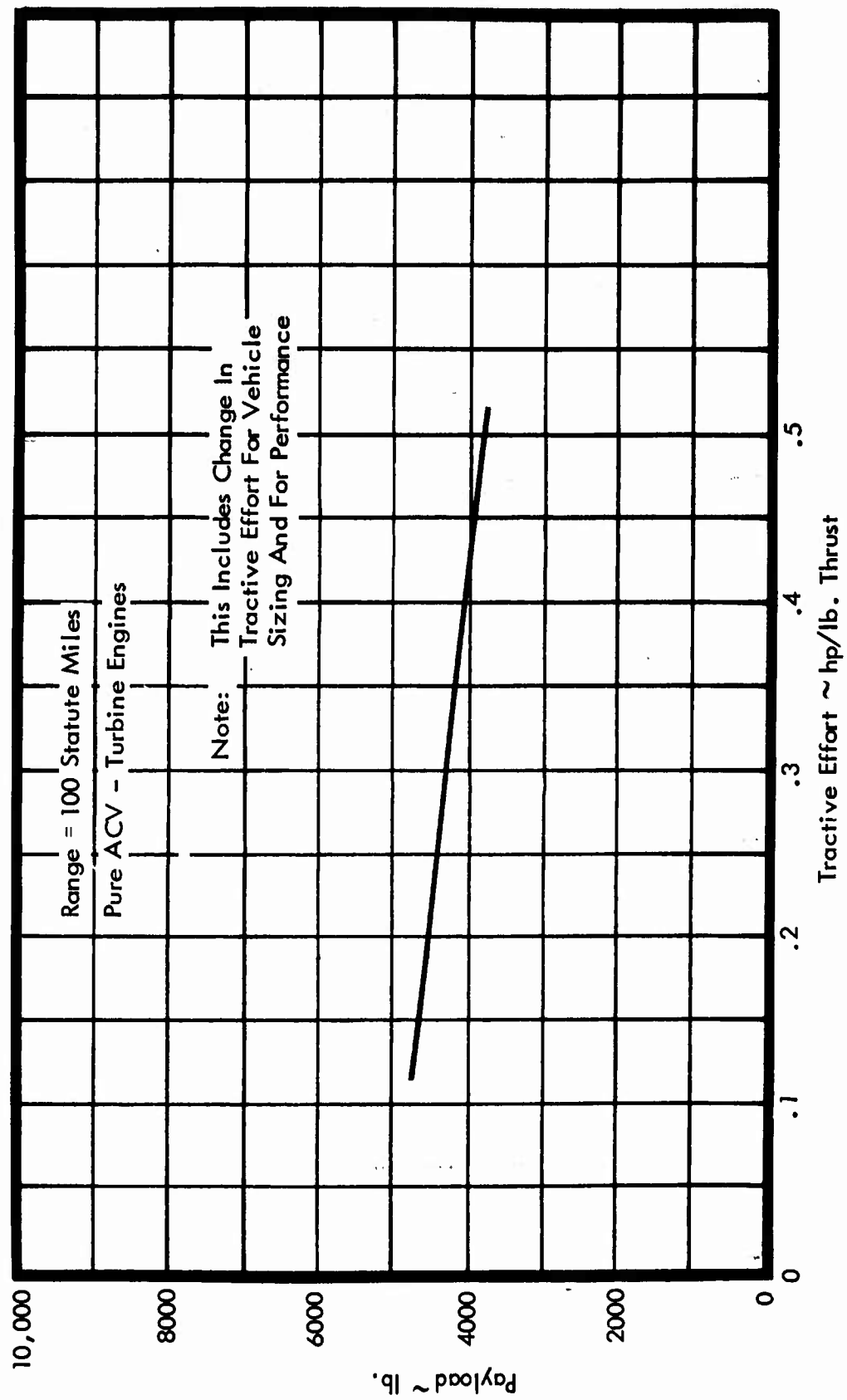


Figure 22. Effect Of Tractive Effort

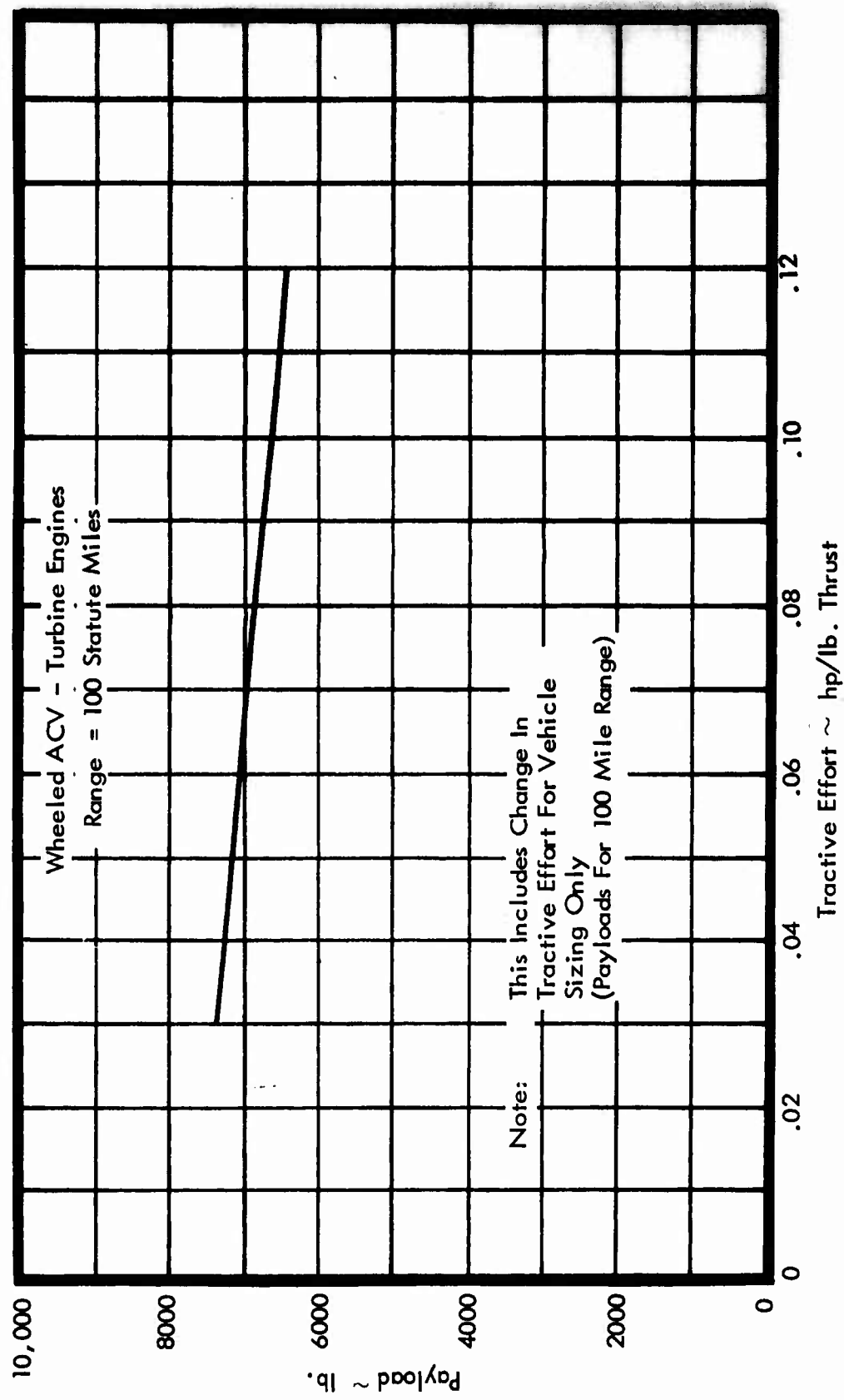


Figure 23. Effect Of Tractive Effort

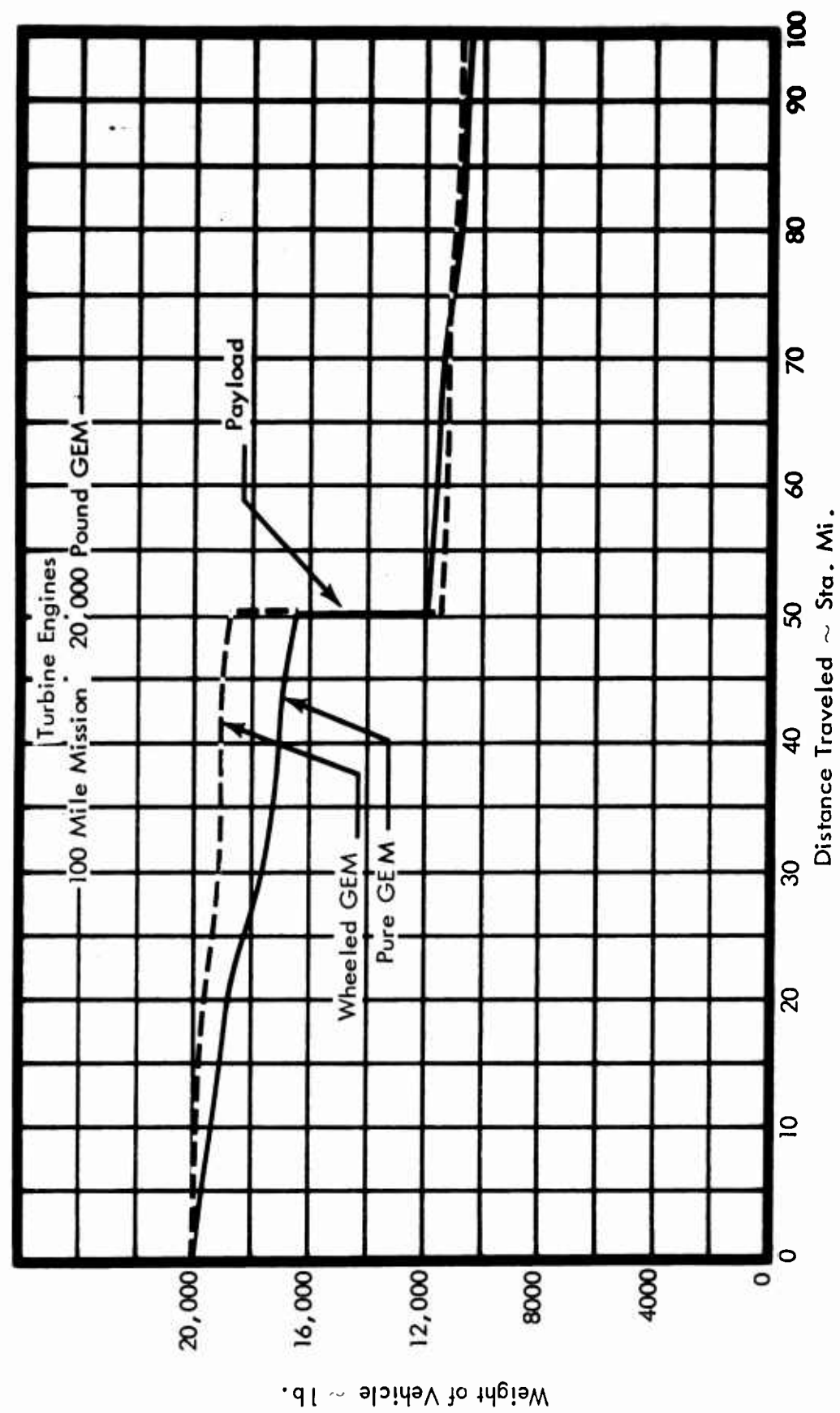


Figure 24. Mission Profile

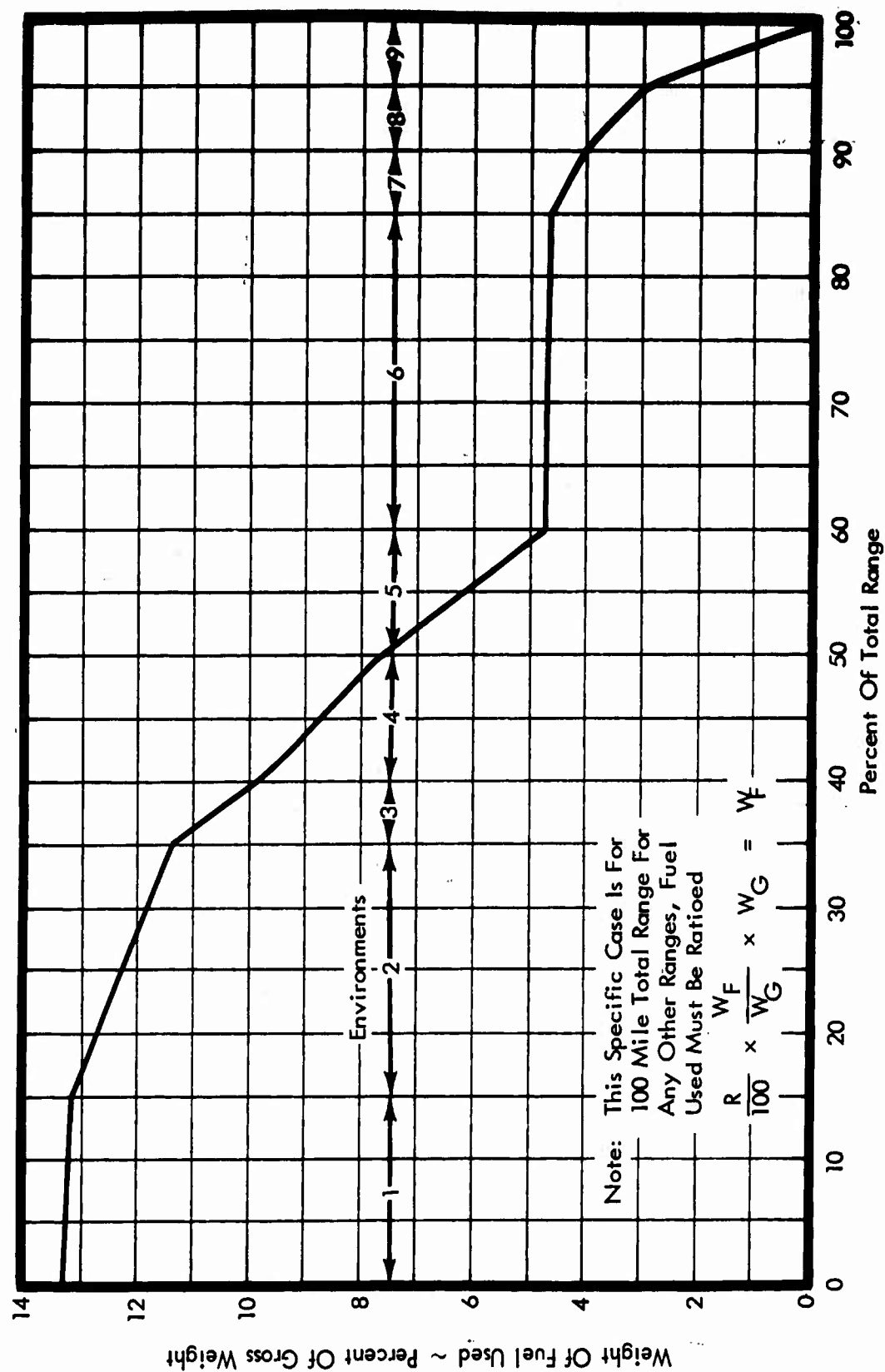


Figure 25. Effect Of Environment On Fuel Usage (Wheeled GEM - Turbine Engines)

of trip is .013 per cent of the gross weight for a 100-mile mission with a 20,000-pound vehicle. The weight of fuel can be expressed as follows for the 75-mile mission:

$$W_F = \frac{R}{100} \frac{W_F}{W_G} W_G$$

curve

or $W_F = \frac{75}{100} (.013) (20,000) = 168 \text{ pounds.}$

In this way, any combination of environments desired may be evaluated, as long as the same speeds are used and the same vehicle characteristics. This also assumes that the vehicle gross weight is 20,000 pounds and that the useful load other than fuel is deposited at the midpoint of the total range. Figure 25 also shows the very large effect of increasing the per cent of weight being lifted, since segments 3, 5, and 9, which have almost all the weight supported by the air curtain, also have the greatest slopes. The effect of placing 100 per cent of the weight on the wheels and traveling over a surface highway is dramatized by the sharp reduction in slope for environment 6.

Such information leads one to wonder what would happen if the velocity in a segment were significantly reduced. Figure 26 shows this effect for the worst condition--a rutted muddy road with a 3 per cent slope and with only 5 per cent of the weight on the wheels. Reductions in velocity of from 5 to 3 miles per hour show little effect. However, the curve does show that a serious problem exists if the velocity gets very low. This is because much fuel is being used just for lifting the vehicle; and if the velocity drops off to such a point that the vehicle requires an exceptional amount of time to traverse the segment, in effect the vehicle becomes bogged down. This could occur if the slope of the terrain increased and caused a resultant decrease in velocity. Other segments of the terrain will not be affected so drastically. For muddy terrain, extreme caution must be employed to keep the vehicle from becoming immobile.

2.8 PERFORMANCE SUMMARY

The BARRINC off-road deterministic model described in this chapter has provided a basis for evaluating the performance of air cushion vehicles. Work recently completed in the industry has been used as

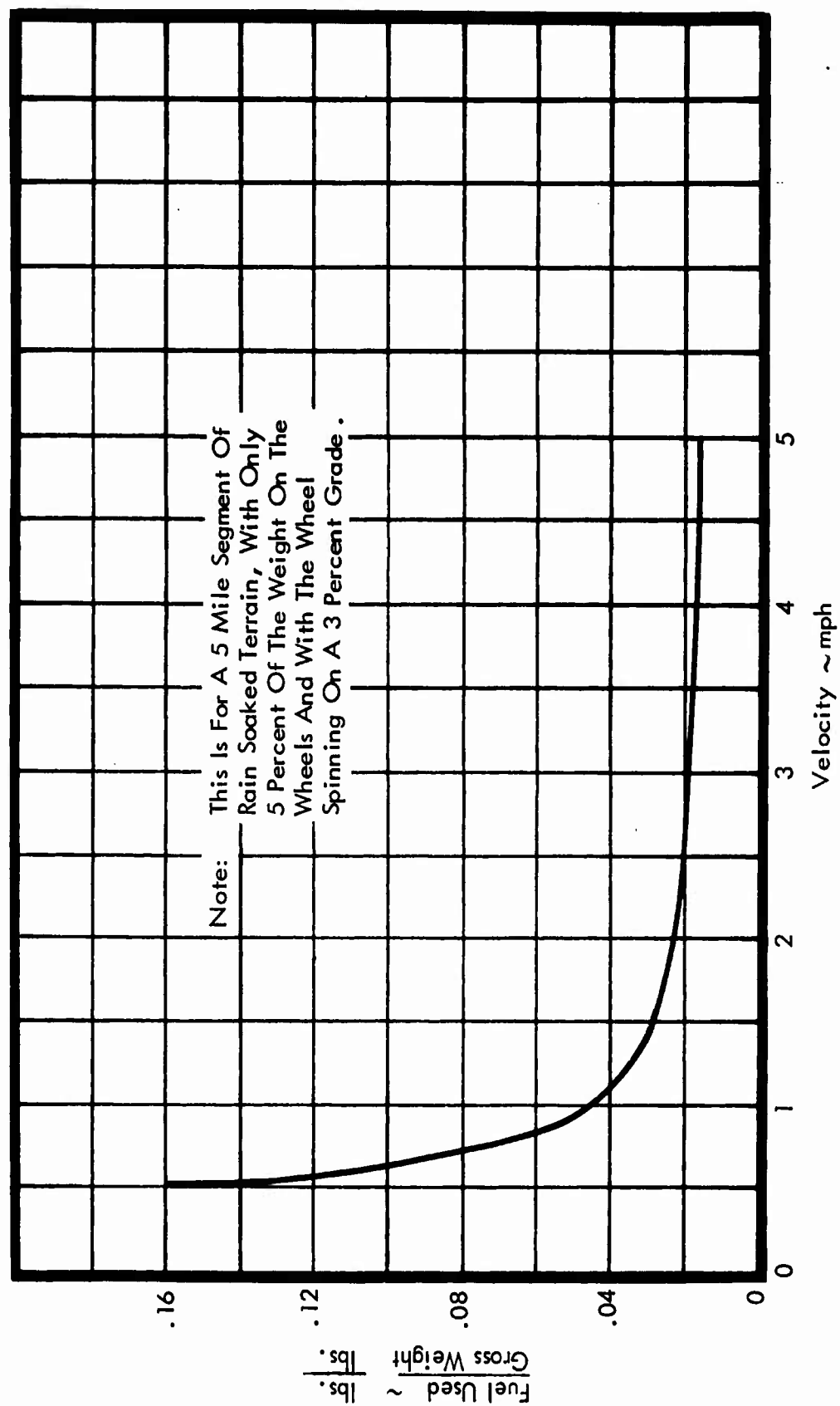


Figure 26. Sample Of The Effect Of Segment Velocity On Fuel Used

the basis for most of the input parameters used in defining vehicles with useful loads of from 40 to 50 per cent of the gross weight. Several of the performance parameters have been varied to show their effects on payload capability.

Results indicated that the larger the vehicle, the better its performance. Size was limited, however, because the vehicle must be air transportable and must operate in environments with trees and natural cover that restrict the length when considering maneuvering capability. As a result, a vehicle with 20,000 pounds of gross weight is near the optimum.

Four nominal vehicles were chosen: a pure ACV with turbine and reciprocating engines and a wheeled ACV with turbine and reciprocating engines. The performance of these four vehicles is shown in Figure 27. As can be seen, the wheeled ACV offers large payload gains over the pure ACV if the ranges are greater than 20 miles. Reciprocating engines show up to advantage at ranges greater than 70 miles.

In considering the performance of an all-around vehicle for army use, where ranges may vary considerably from one task to the next, it is apparent that the wheeled ACV with reciprocating engines will be the most versatile vehicle. Penalties which it incurs at short range are small when considering its much greater capability at long ranges.

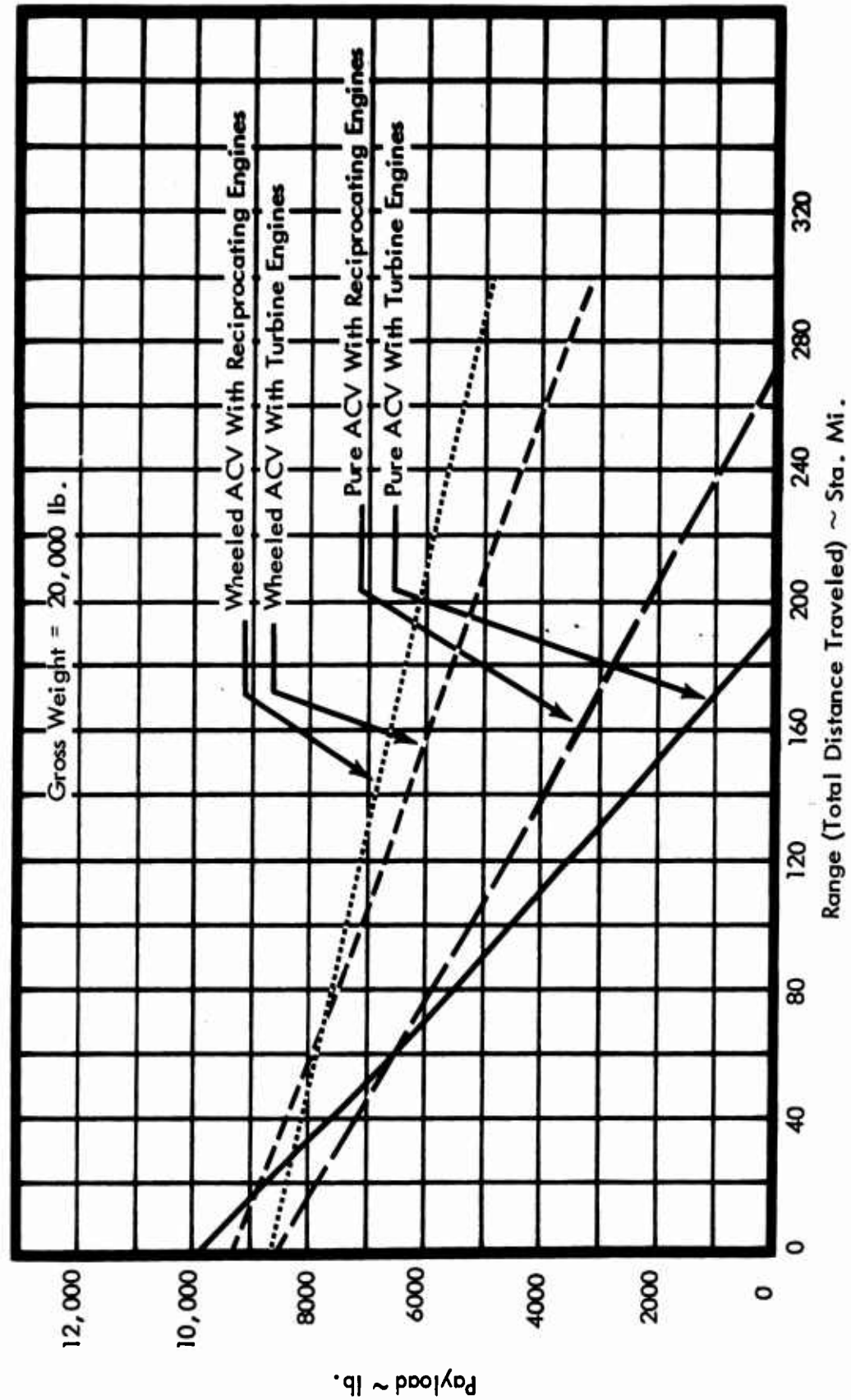


Figure 27. Performance Summary

CHAPTER III

AIR CUSHION VEHICLE COSTS

3.1 COST METHODOLOGY

At the time of this report, there is no established cost methodology for evaluating initial investment costs or the operating costs of air cushion vehicles (ACV's). This is, of course, due to the relatively small number of machines built to date. Costs of the engineering, fabrication, and development phases of those vehicles have, however, followed the general framework peculiar to the design and construction of many subsonic transport aircraft. Initial investment costs can therefore be expected to show the same variations with quantity production as simple transport aircraft constructed by the aircraft industry. Use of current Air Transportation Association and Society of British Aircraft Constructors methods for computing direct operating costs is considered permissible, providing appropriate modifications are incorporated to account for the differences in configurations, environment, and use between commercial operations and a military environment.

This chapter has been prepared to serve as a background and basis for defining values of selected ACV's for the over-all economics analysis in the next chapter. As such, it is believed to include the latest available information on the over-all costs of currently operating ACV's and how these costs may be modified when military requirements must be satisfied.

The cost of the first vehicle of any type will include the following:

- Engineering costs
- Development costs (tests, etc.)
- Tooling costs
- Engine costs
- Fabrication and assembly costs
- Experimental operating costs
- Profits.

Production costs may be derived from "learning curves", long established over a variety of previous equipments. These curves are dependent upon the complexity of the new vehicle, relative to previous experience, and the anticipated quantities to be produced. They are based on the assumption that the cost of fabricating the second and subsequent vehicles is lowered by the degree of learning acquired as the vehicles are built, and continues to be reduced to an asymptotic level at some relatively large production level.

In the case of the ACV, the most significant parameter in evaluating design and construction costs is the empty weight of the vehicle and, in particular, the structure weight. Stanton-Jones (Reference 8) and Hughes (Reference 37) have evaluated the importance of structure weight by placing a price tag on the cost of saving 1 pound of empty weight. They claim that from a commercial operators point of view, it is worth paying up to 60 dollars to save 1 pound of empty weight. This attention to saving weight has been the major reason why ACV design has followed aircraft practice; in fact, up to the present time, neglecting several superficial attempts to build small ACV's, the only builders of these vehicles are aircraft-oriented companies, such as:

Bell Aerosystems	U. S. Navy Hydroskimmer
Ford Aeronutronic	Experimental ACV - off-road
Douglas Aircraft Co.	Experimental ACV
Reynolds Aluminum	Everglades Speedster
Martin-Marietta	Recirculation GEM
Saunders-Roe	SRN1, SRN2, SRN2 MkII, SRN3
Vickers-Armstrong	VA-1, VA-2, VA-3, Landrover off-road vehicle
SAAB	Type 401
Folland Aircraft	GEM I and II
Krasnoye Sormovo	River Launch ACV
Hawker Siddeley Canada	Gemini off-road vehicle

With this preponderance of ACV activity in the aircraft industry, and with the emphasis on weight reduction, it is extremely unlikely that significant numbers of future ACV's will be developed in other industries, with the exception of those craft configured with physical sidewalls for relatively slow operating speeds in shallow rivers. However, even in these cases, empty weight will be controlled and reduced wherever possible, for the main advantage of these craft is still the high disposable load as a proportion of the gross weight.

With this aircraft oriented background, it is believed that relatively reliable assumptions can be made with respect to initial investment costs and operating costs of future ACV's.

3.2 INITIAL INVESTMENT COSTS

Development Costs. Development costs are those costs incurred in producing the first vehicle of a type and include research, development, test, and evaluation (RDT&E). From various published and unpublished data, it is possible to establish a relatively accurate curve of the initial costs of producing commercial ACV's. Figure 28 presents the costs of the first vehicle of a particular type and includes all costs associated with producing the first prototype. The following craft are included:

Britten-Norman	CC-2
Ford Aeronutronics	Experimental skirted ACV
Vickers-Armstrong	VA-3
Bell Aerosystems	Hydroskimmer
Westland Aircraft	SRN2

The costs obtained from sources in the United Kingdom have been modified to reflect the costs as they would have been incurred in the United States. The current exchange rate was used and the results multiplied by 1.6 in order to approximate the relative difference in wages and salaries.

To use these data, one must read the first cost of the complete vehicle and divide it by the number of vehicles to be produced to provide an RDT&E cost to be included in the initial investment costs. For instance, for a vehicle with a 20,000-pound gross weight, the RDT&E costs are \$1,070,000. For a total buy of 150 vehicles, the RDT&E cost per vehicle becomes:

$$\text{RDT\&E per vehicle} = \frac{\$1,070,000}{150} = \$7,150 .$$

In effect, RDT&E costs of the first vehicle have been amounting to about \$100 per pound of empty weight, a figure which checks very well with these data. The dashed line in Figure 28 shows in a very approximate manner how the structure and equipment costs relate to the over-all vehicle costs.

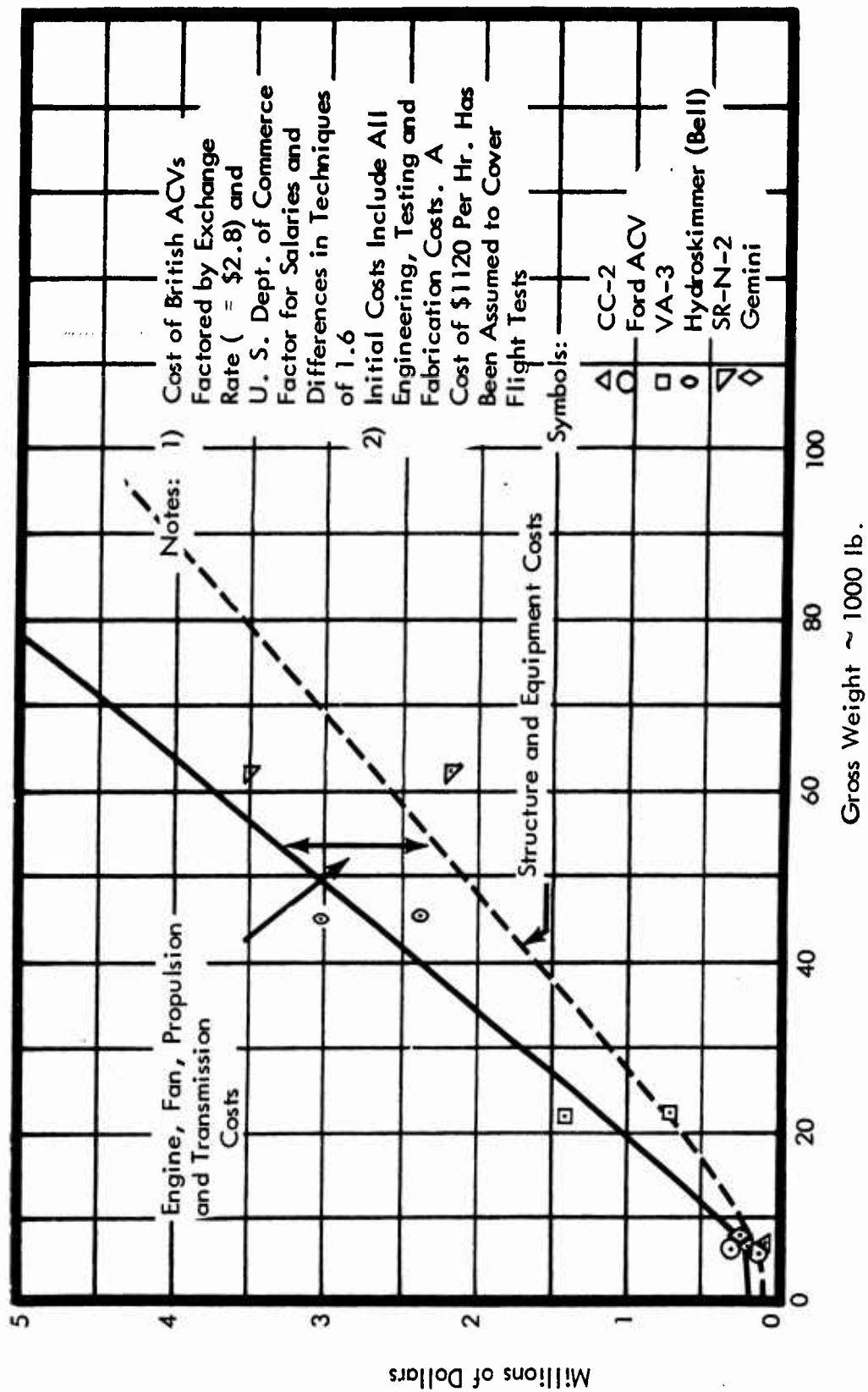


Figure 28. Initial Costs of Current ACVs

Structures Costs. The development of reliable cost data for military equipment structure is dependent upon the following variables:

1. Type of structural forms
2. Type of materials used
3. Manufacturers experience with 1 and 2
4. Degree of complexity relative to 3
5. Quantities to be produced

In Reference 38, state-of-the-art data on ACV structural forms and materials in general use were developed. It was found that both commercial and military ACV's designed predominantly for over-water operation were using aircraft forms and materials to produce lightweight, efficient structures and that, dependent upon the operating philosophy of the designer, a wide variety of criteria was being used for stressing purposes (Reference 31). In the case of ACV's configured for over-land operation, such as the Bertin multiplenum-chamber machine--the TERRAPLANE, the Ford Aeronutronic Experimental ACV, and the Vickers-Armstrong Landrover conversion, structural forms are much simpler and the materials used tend towards commercial grades and thicknesses. Both the Ford and Bertin machines incorporate a basic torsion box structure, and the Landrover conversion kit is made up from relatively thick light-alloy plates and boundary members. Based on the cushion areas of these vehicles, the structure weights are estimated as follows:

Bertin TERRAPLANE	10 lb. /sq. ft.
Ford Exp. ACV	7 lb. /sq. ft.
Vickers Landrover conversion	
kit only	10 lb. /sq. ft.
Vickers Landrover total	36 lb. /sq. ft.

From these estimates, it can be seen that there are considerable differences between the structural concepts of Bertin, Vickers, and Ford and those associated with the Rover Motor Company which produces the basic Landrover. It is therefore obvious that a common standard must be devised for this study to cover the overland ACV's considered, in order that rational costs may be determined.

In order to obtain realistic cost estimates for the structure of overland ACV's with or without wheels, the following will be assumed:

Vehicle width	10 ft.
Vehicle length	20 ft.
Vehicle payload loading	75 lb. /sq. ft.
Vehicle cushion pressure	100 lb. /sq. ft.
Vehicle operating height	3 ft.

If it is assumed that the load is uniformly distributed over each vehicle's planform and that the vehicle is dropped vertically from its maximum operating height to points on the ground at the vehicle extremities, it is believed that this will produce the maximum bending moment the vehicle can sustain within the speed range of overland vehicles. It will also be assumed that under this condition, the decay of the cushion and collapse of any trunk or skirt will reduce the free-fall height by one-half. The stopping distance will be in accordance with normal dry, hard terrain and the general disformation patterns associated with crash conditions; a stopping distance will therefore be established at .33 foot.

Therefore, from a free-fall height of 1-1/2 feet and a stopping distance of .33 foot, the velocity impact will be 10 feet/second and the acceleration in g's for rigid bodies will be 10g.

Using a maximum planform area of 200 square feet and a maximum payload of 75 pounds/square foot, together with a disposable load to gross weight ratio of 50 per cent, the maximum load arising from this condition will be 300,000 pounds on the CG of the vehicle.

Longitudinal strength may be simply determined: $A = \frac{M}{df}$, where A equals area of capping materials, M equals maximum bending moment, d is the distance between caps, and f is the allowable stress. Therefore,

$$A = \frac{18,000,000}{12 \times 20,000} = 75 \text{ square inches.}$$

With a structure width of 120 inches, a single plate of .58-inch thickness would be required top and bottom. With alclad at .101 pound/cubic inch, the weight of the cappings would be as follows:

$$\begin{aligned} W_{\text{caps}} &= 75 \times 240 \times 2 \times .101 \\ &= 3,636 \text{ pounds.} \end{aligned}$$

If 10 per cent of the total capping weight is added for webs and secondary fittings to this estimate, a reasonable guide can be obtained for the total primary structure required to meet the assumed criteria. A weight of 4,000 pounds will therefore be assumed to cover the primary structure for a vehicle measuring 10 by 20 feet. The weight per square foot of planform area will be taken as 20 pounds per square foot.

To establish, with reasonable accuracy, the cost of fabricating light-alloy structures, it is necessary to draw on the experience of the aircraft industry, particularly with respect to the manufacturers of subsonic vehicles. From this experience, degrees of complexity relative to the learning curves to be used in the cost of fabricating ACV's can be estimated.

From an analysis of the bare airframe costs of post World War II aircraft, a value of \$11 to \$24 per pound can be obtained, such values having been corrected for 1962 cost-of-living indices. Learning curves for these aircraft vary between 70 per cent and 90 per cent. However, it should be noted that although these aircraft are relatively uncomplicated by modern standards, in comparison with both over-water and over-land ACV's, they are considerably more complex. This is particularly true with respect to quality control standards used, fabrication processes, and other refinements unnecessary in ACV development.

Based on information from European and U. S. manufacturers, the cost/pound of the VA-1, VA-2, VA-3, SRN1, SRN2, CC1, CC2, SAAB 401, GEM I and II, Bell Hydroskimmer, and Bertin TERRAPLANE can be approximated. When these data are suitably factored by a U. S. Department of Commerce factor of 1.6 to account for wage differentials and production know-how, a cost per pound for the first production vehicle of \$22.40 can be obtained. An 80 per cent learning curve is used for production quantities. Based on this, the variation of cost for production quantities of ACV's may be estimated in keeping with Figure 29, where the cumulative average curves are used to define the average costs of all units up to the number of interest. For instance, the cost of the 150th vehicle is \$4.45 per pound, while the average cost of the first 150 vehicles is \$6.45 per pound. The meaning of this in terms of total dollars is shown in Figure 30.

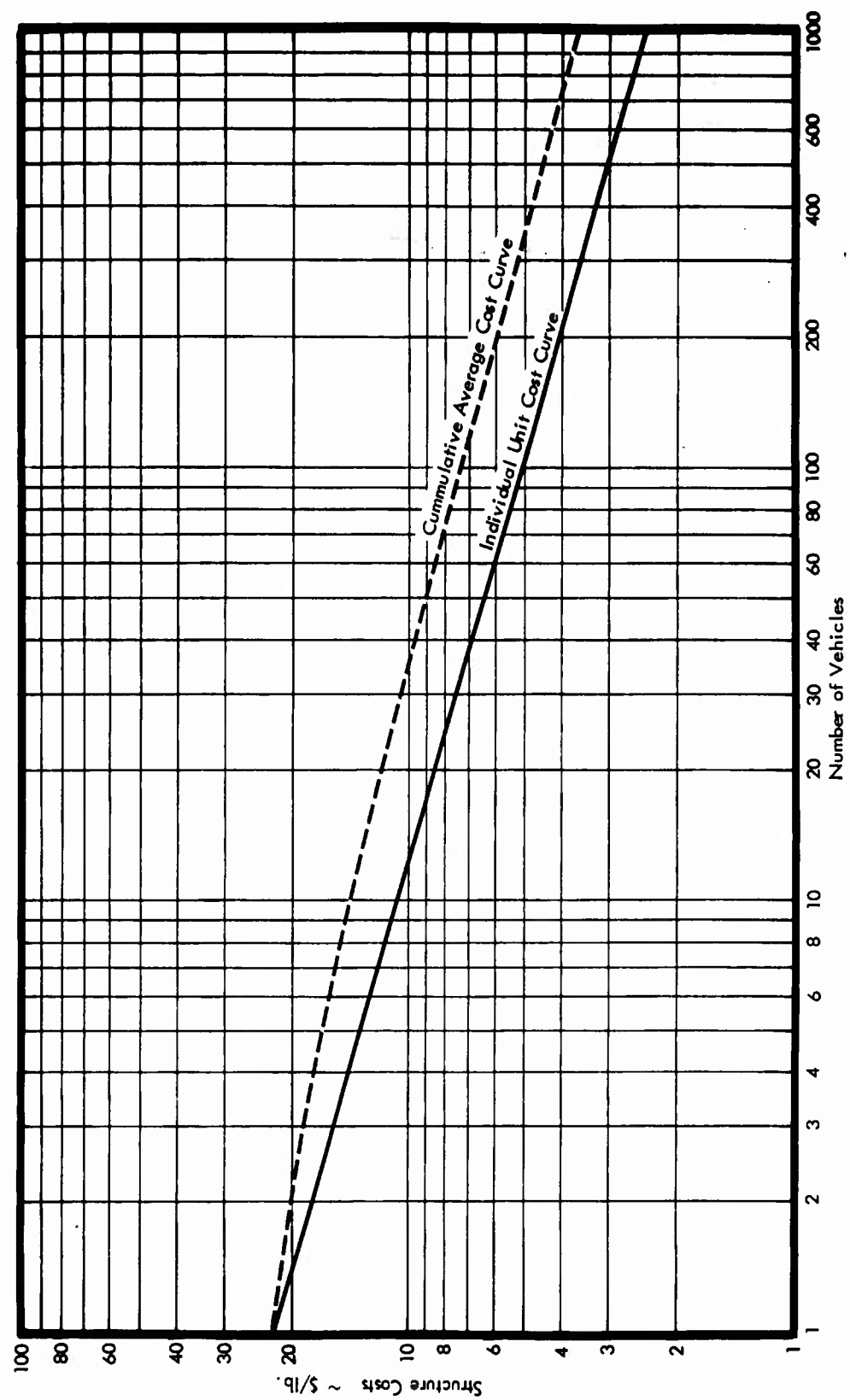


Figure 29. Production Costs Of Structures

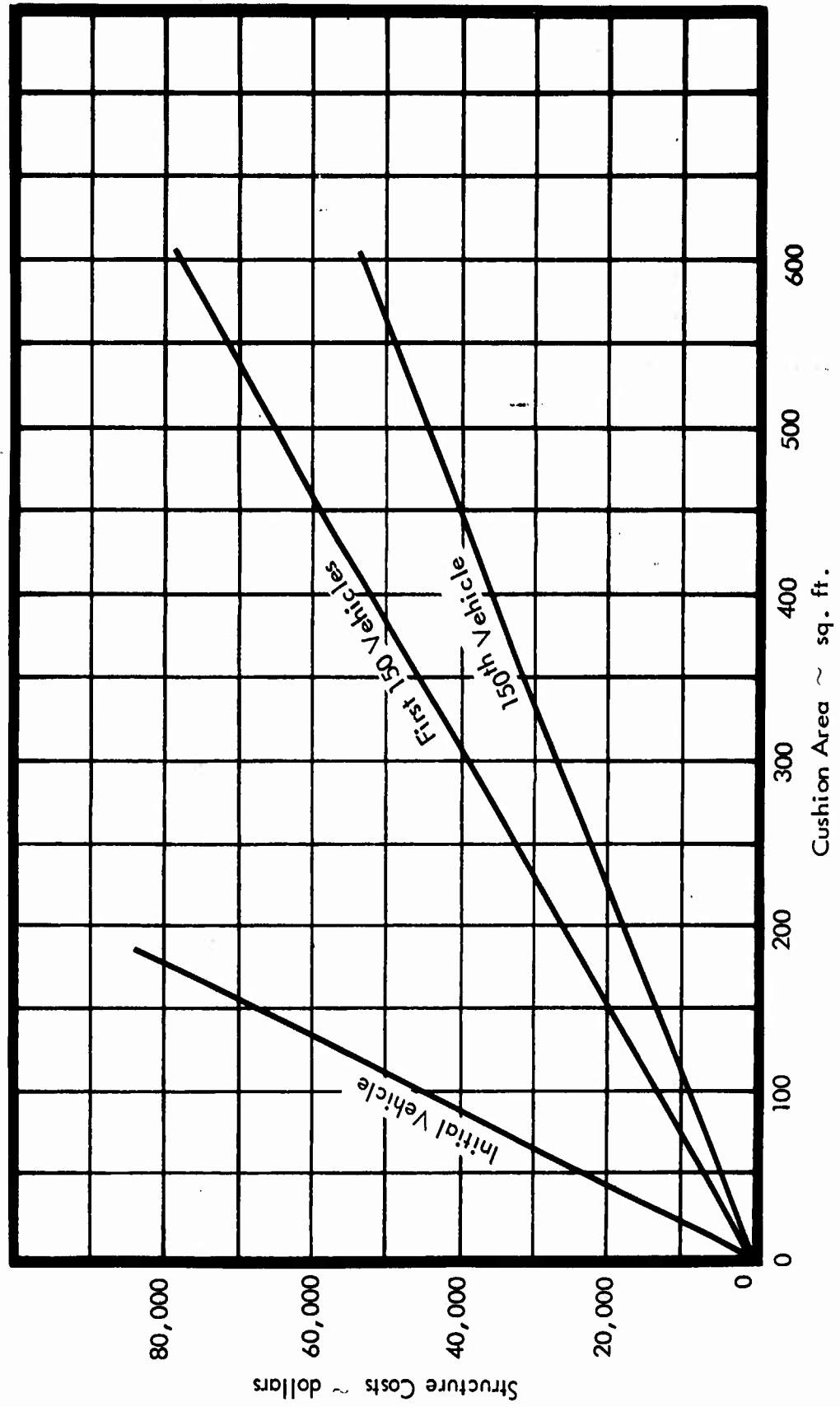


Figure 30. Structure Costs

Although the vehicles used for the logistics problem may have somewhat different dimensions than were chosen for this analysis, it is considered that although, generally speaking, the vehicles will be longer, the payload will be lighter density. Therefore, the costs as developed may be regarded as typical for all ACV vehicles to be considered for this study.

Power-Plant Systems Costs. The power-plant system may be separated into two components for cost analysis purposes: engine costs and associated hardware costs, such as lift fans, ducting, and propelling mechanisms.

Engine costs are known to vary with horsepower of the engine. Figure 31 presents this variation of cost with size. Two turbine-engine costs are shown, one for limited production of engines, which includes the research and development costs, and a second curve showing turbine costs for large-scale production. Past experience has shown that the turbine engine does not decrease appreciably in cost for large production runs due to constant upgrading of these engines; but this same upgrading increases the horsepower, so, in effect, the result is a reduction in cost per horsepower. However, for this report, the curve for small-volume production has been used, since the ACV is a rather new application for turbine engines and since it will probably require new development for system operation.

The short dashed line in Figure 31 shows typical values used for reciprocating engines. These values are not the lowest which can be anticipated for very large scale production but are values consistent with current reciprocating-engine programs.

The associated hardware costs will vary with the amount of power available in the system. In this analysis, it is assumed that the cost of assembling the propelling hardware is the same as that for the lift hardware, and that this cost will be \$30.00 per horsepower. This is very similar to the value of \$28.00 per pound used in Reference 16. This value is independent of the size of the engine and will be used as a constant over the range of engines. However, these components are subject to normal aircraft production techniques, and again an 80 per cent learning curve will be assumed, as shown in Figure 32. These values will be applied to both wheeled and pure ACV's. In this respect, it should be noted that, although the suspension-propelling systems of a wheeled ACV will weigh more than the propelling system

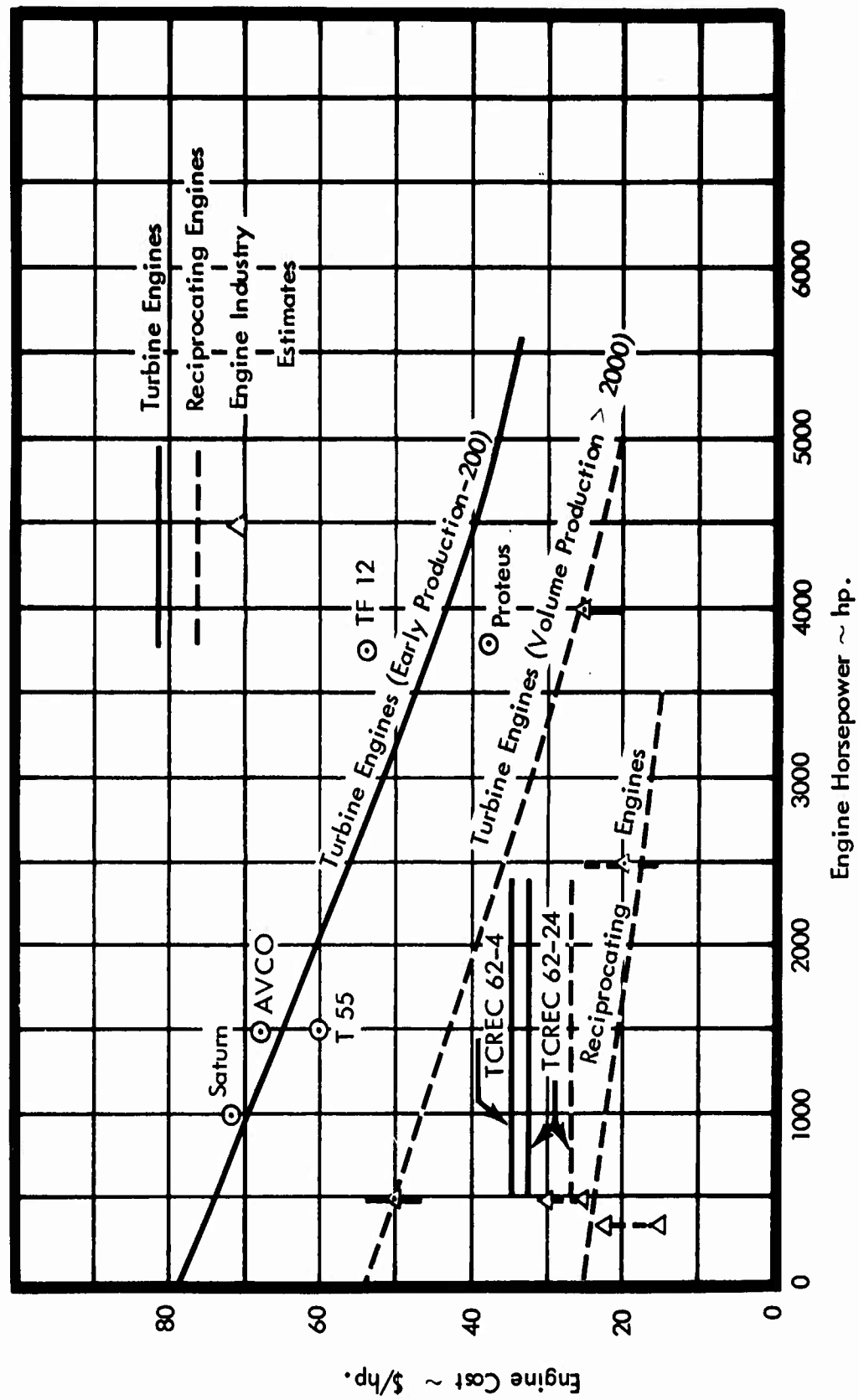


Figure 31. Engine Costs

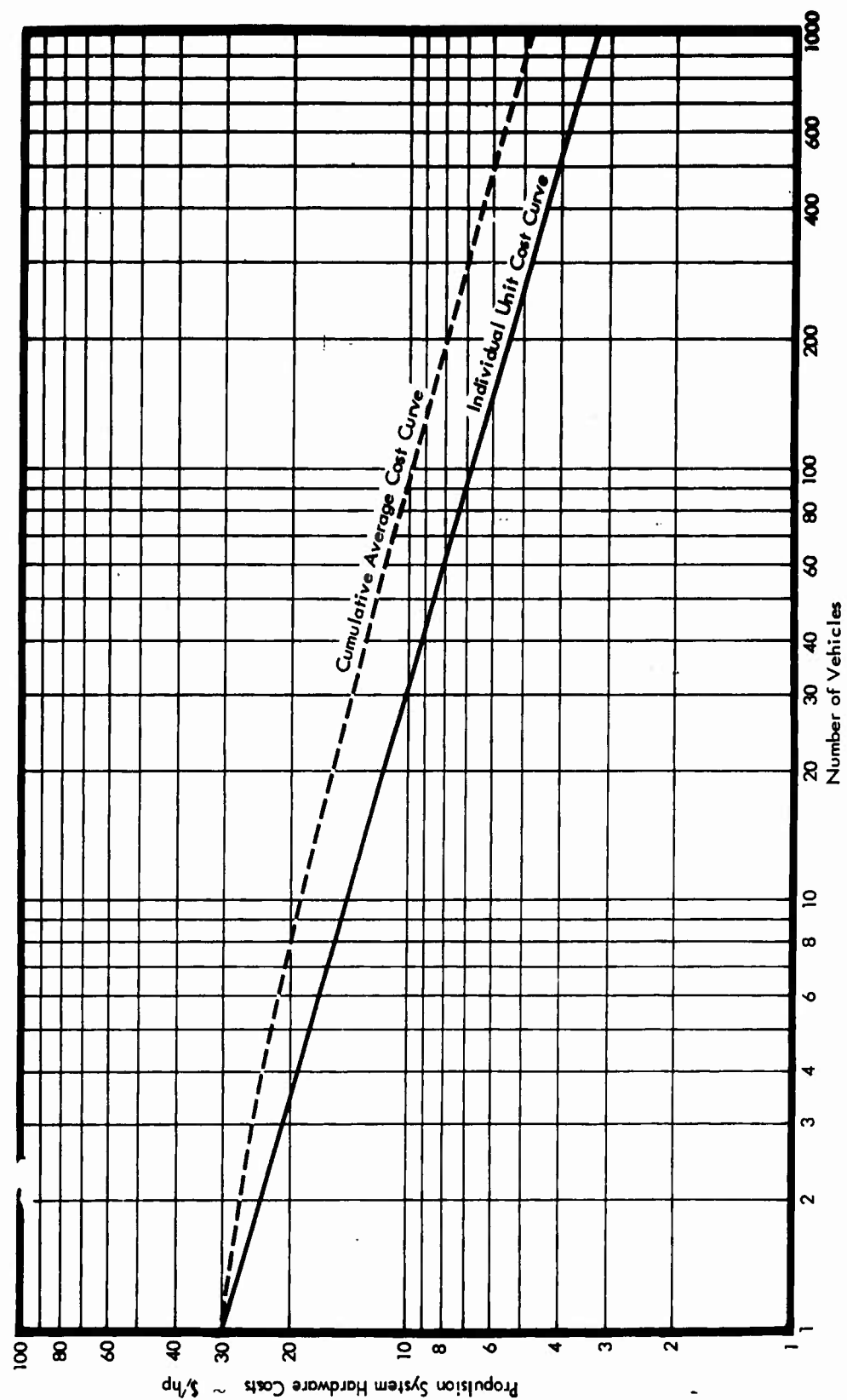


Figure 32. Propulsion System Hardware Costs

of the pure ACV, the cost per pound of the wheeled system will be less.

To illustrate, assume that 150 vehicles are to be built, each of which will require 2,000 horsepower. Then:

Engine costs 60 x 2,000	=	\$120,000
System hardware cost 8.7 x 2,000	=	17,400
Total propulsion system costs	=	\$137,400

In actual practice, there will be many small engines employed in each vehicle rather than one large one. One reason for this is space. But even more important, the fuel consumption in terms of pounds of fuel per brake horsepower increases very rapidly when less than full power is used. It would be more economical to obtain 500 horsepower from a 2,000-horsepower capability by shutting off three engines than by reducing the power of one engine to one-fourth of its capability. For this reason, the maximum sized engine will be 500 horsepower. It also is assumed that engines will be installed in pairs, for weight and balance considerations. Therefore, the engines used will have the largest horsepower which can be obtained by dividing the required horsepower by an even number and still not exceeding 500. For instance, if 2,250 horsepower is needed in a machine, it is assumed that there will be six gas-turbine engines of 375 horsepower; and the cost will be \$75.00 per horsepower times 2,250 horsepower.

It should be noted that these propulsion system costs are less than half the value shown in Figure 28. This is entirely due to the fact that the values shown in Figure 28 include the engineering costs associated with installing the propulsion system. These costs are normally included in the RDT&E costs and are prorated over the number of vehicles built.

Equipment Costs. For the purpose of this study, the crew will be included in the weight assumed for equipment. With a crew of two, a weight of 400 pounds will be allocated. The rest of the equipment will include seats, instruments, batteries, lights, tools, and navigation and communications equipment. Most of these equipments are not expensive--on the order of 2 to 5 dollars per pound of weight. However, it is assumed that each vehicle will have a good communications system and adequate navigation equipment; and although these items are not heavy, they are expensive. For this reason, a cost of

10 dollars per pound has been assumed. If total equipment is assumed to be approximately 5 per cent of the gross weight of off-road air cushion vehicles, equipment including crew will weigh 1,000 pounds, for a vehicle weighing 2,000 pounds. Based on \$10/pound, equipment for this vehicle will cost \$6,000, half of which is for communications.

Summary of Investment Costs

To summarize the initial investment costs, a sample calculation covering a 20,000 pound ACV fitted with gas turbines follows:

Total number of vehicles	=	150	
Horsepower per vehicle	=	2,000 (turbine engines)	
Number of engines	=	4	
Horsepower per engines	=	500	
Gross weight of vehicle	=	20,000 pounds	
Structure weight	=	4,000	
RDT&E costs per vehicle	=	<u>1,070,000</u>	= \$ 7,150
		150	
Structure costs per vehicle	=	4,000 (\$6.45)	= 26,600
Engine costs per vehicle	=	2,000 (\$73.7)	= 147,400
Propulsion system hardware per vehicle	=	2,000 (\$8.65)	= 17,300
Equipment costs	=	600 (\$10.0)	= <u>6,000</u>
Initial investment cost per vehicle			= \$204,450
Total initial investment cost for 150 vehicles			= \$30,667,500

This example shows the values which must be assumed or determined from the systems performance and the resulting initial investment costs.

3.3 OPERATING COSTS

Operating costs include all costs which are associated with vehicle operation. These costs should be determined for the complete life of the vehicle, which is then divided by the number of years in operation to obtain the annual operating costs. Operating costs for a military vehicle are made up of the following:

1. Maintenance costs
2. Fuel costs
3. Personnel costs
4. Attrition costs.

These may be supplemented by such items as transportation costs, training costs, and command overhead costs in determination of the complete system operating costs. These supplementary items are normally some percentage of the four major operating costs above and are not included in this analysis since they would require a more specific definition of the theater of operations and the construction of a specific situation.

Maintenance Costs. At the present time, no uniform technique has been developed to determine the maintenance cost of ACV's due to the fact that there are no operational vehicles available to supply this data. Many different assumptions have been made throughout the air cushion literature, assumptions which are influenced primarily by the type of operation considered. In most cases, maintenance costs have been estimated as a percentage of initial costs. For instance, in Reference 30, the maintenance cost of an ACV was assumed to be 20 per cent of the initial cost over an operational life of 5,000 hours. Doubling this for an operational life of 10,000 hours, total maintenance costs become 40 per cent of the initial costs. Another source, Reference 17, uses a cost of 15 per cent of the initial cost per year for an annual peacetime utilization of 485 hours, or 310 per cent of the initial cost for a 10,000-hour utilization. At the rate of usage, this would mean an operational life of 21 years. It would seem that considering the average speeds associated with this mission, the utilization per year should be considerably more than 480 hours, even in peacetime. This will mean a very sizeable reduction in maintenance costs. Still another source, Reference 16, has used an annual maintenance cost of 50 per cent of the initial cost per year for an annual utilization of 4,750 hours, or a total maintenance cost of 105 per cent of initial cost over the life of the vehicle. This cost was based on data for typical amphibious vehicles with initial costs much less than an ACV. As can be seen from these sources, opinions vary considerably.

To put more substance into this cost estimate, the methods developed by the Air Transportation Association and the Society of British Aircraft Constructors have been employed. These costs are based on

typical airline operations and, as such, are not directly applicable to this particular mission. However, they do present a systematic technique for including variations in vehicle design components and offer a foundation for final maintenance costs. The development is shown in Table 17, where operational life is assumed to be 10,000 hours and the period between engine overhauls is assumed to be 2,500 hours. Aircraft costs were based on a total buy of 150 aircraft.

The results shown indicate that the total maintenance costs of the vehicle would be on the order of 20 per cent of the initial cost. For field army operations, this does not represent a very realistic situation. These costs have been developed for the maintenance of relatively standard aircraft under ideal conditions. For field operations with a relatively new machine, and with personnel who have not spent a lifetime in this work, these costs might double or triple. It does not seem unreasonable, then, to assume a factor of 50 per cent of initial costs as the maintenance cost over the life of the vehicle. This value is somewhat higher than the lowest of the three cited above. To achieve this, careful attention must be paid to designing for ease of maintenance in the vehicle development.

Fuel Costs. The costs used for fuels also vary somewhat in the air cushion literature, but they are of the same general magnitude. Data in Reference 39 present the costs and specific weight for army vehicles. Civilian costs and weight are shown in Reference 40. Other costs are shown in Reference 39. Since these are all of the same order of magnitude, the typical values shown below will be used as representative in this operation.

<u>Fuel</u>	<u>Cost per gallon</u>	<u>Weight per gallon (lb)</u>	<u>Cost per pound</u>
Gasoline	\$.15	6.0	\$.0250
Kerosene	.09	6.8	.0132
JP-4	.09	6.4	.0141
Diesel	.09	6.9	.0130

Oil costs were considered, but values in the above-referenced reports indicate that the cost of oil is comparatively very small. In fact, Reference 39 indicates that the oil cost of turbine engines is negligible while reciprocating engine costs were in the order of 1 to 6 cents per hour of operation. Oil costs in Reference 40 are in

TABLE 17
ATA MAINTENANCE COSTS

Gross weight, lb.	12,000	20,000	24,000	12,000	20,000
Empty weight, lb.	6,700	10,220	12,000	7,840	10,790
Weight of engines, lb. (.6 lb/hp)	930	1,450	1,600	485	715
Empty weight without engines, lb.	5,770	8,770	10,400	7,355	10,075
Number of engines	4	6	6	2	4
Horsepower per engine	387	403	445	403	298
Total horsepower	1,548	2,417	2,670	807	1,190
Block speed mph	9.1	9.1	9.1	11.4	11.4
* Cost of vehicle without engines	\$ 39,150	59,850	68,600	35,380	53,500
Cost of engines (each)	\$ 28,900	30,000	32,900	29,800	22,500
* Total cost	\$ 154,750	239,850	267,000	94,980	143,500
Labor cost - vehicle without engines	11,820	12,230	12,730	9,550	10,110
Labor cost - engines	3,780	5,760	5,850	1,540	2,970
Materials cost - vehicle without engine	3,170	3,170	3,170	2,530	2,530
Material cost - engine	6,610	10,960	12,020	2,920	3,890
Applied maintenance burden	19,400	22,600	24,100	12,600	15,800
Total maintenance costs	44,780	54,720	57,870	29,140	35,300
* Maintenance, per cent of initial cost	.29	.228	.216	.307	.246
* No RDT&E has been included -- for 150 vehicles with turbine engines.					

the order of 4 per cent of the fuel costs for reciprocating engines and 5 cents an hour per engine for jet engines. Since these costs represent such a small portion of the over-all systems cost and since they are in any event proportional for all vehicles, they will be neglected in this analysis.

Personnel Costs. The man-hour costs have been obtained from Reference 64, where the cost per man in the Army was \$11.43 per 10-hour working day. This value of \$14.30 per hour was used in Reference 16, while a value of \$1.66 was used in Reference 39 for maintenance personnel. This last value is assumed to be for the more standard 8-hour working day. For a wartime situation, a 10-hour working day is not unusual, so the cost of \$1.43 per hour appears justified for this operation. In all cases, a two-man crew has been assumed. Personnel costs used are as follows:

$$\$1.43 \times 10,000 \times 2 = \$28,600 .$$

This is for the entire operational life of the vehicle.

Attrition Costs. It is considered impractical to define attrition costs during an estimated wartime situation, as so much will depend upon the actual situation.

If the vehicle is in the front lines or is subject to air attack, significant attrition is probable. The values to be used here will be based on the assumption that the vehicles are operating in a theater of war away from active enemy attack. In such situations, some vehicles will be lost, due to collisions and other accidents. For this analysis, a value of 10 per cent of the initial cost of the vehicle will be used as the rate of attrition over the life of the vehicle. A similar value has been used in Reference 16.

Summary of Operating Costs

A typical calculation of operating costs covering a 20,000-pound ACV powered with gas turbines is estimated as follows:

Number of vehicles	150
Utilization	10,000 hours
Gross weight of ACV	20,000 pounds
Production cost of ACV	\$239,850

Initial cost of ACV	\$247,000
Fuel used per mile	53.70 pounds
Average velocity	9.1 mph
Fuel used per hour	489 pounds
Fuel cost per hour (turbine engine)	\$6.90
Maintenance cost (\$239,850 x .50)	\$119,900
Fuel costs	\$ 69,000
Personnel costs	\$ 28,600
Attrition costs (\$247,000 x .10)	\$ 24,700
Total operating costs (vehicle lifetime)	\$242,000

The total cost of building and using one of a total of 150 ACV's for 10,000 hours is the \$247,000 plus \$242,000, or \$489,000.

3.4 TOTAL VEHICLE COSTS

The costs which have been defined in this chapter have been used as the basis for air cushion vehicle costs in the cost/effectiveness comparison in the following chapter. Four configurations have been chosen for this analysis and the cost breakdown is shown in Table 18. Configurations 1 and 2 are for pure ACV's with turbine and reciprocating engines, and configurations 3 and 4 are for wheeled ACV's with turbine and reciprocating engines. Total costs shown are for the life of the vehicles. These costs are representative of what might be expected for a newly designed vehicle in limited production.

TABLE 18
COST OF AIR CUSHION VEHICLES

Configuration	1	2	3	4
Type	PURE ACV		WHEELED ACV	
Engines	turbine	reciprocating	turbine	reciprocating
Utilization, hr.	10,000	10,000	10,000	10,000
Number of vehicles to be purchased	150	150	150	150
Gross weight, lb.	20,000	20,000	20,000	20,000
Zero-range payload, lb.	9,783	8,575	7,109	7,368
Structural weight, lb.	5,109	5,109	5,772	5,772
Total horsepower, hp.	2,417	2,417	1,190	1,190
Number of engines	6	6	4	4
Horsepower per engine, hp.	403	403	298	298
Fuel used per mile, lb./mi.	9.1	33.3	20.95	12.39
Average velocity, mph	9.1	9.1	11.4	11.4
Fuel used per hour, lb.	489	303	249	141
Total fuel used (10,000 hr), lb.	4,890,000	3,030,000	2,490,000	1,410,000
Cost factors:				
Structure, \$/lb.	6.45	6.45	6.45	6.45
Engine, \$/hp.	74.30	23.90	75.30	24.10
Propulsion system hardware, \$/hp	8.65	8.65	8.65	8.65
Fuel costs, \$/lb.	.014	.025	.014	.025
Production costs:				
Structures	\$ 33,000	33,000	37,200	37,200
Engines	\$179,400	57,800	89,500	28,700
Propulsion hardware	\$ 20,900	20,900	10,300	10,300
Equipment	\$ 6,000	6,000	6,000	6,000
Total	\$239,300	117,700	143,000	82,200

TABLE 18 (continued) COST OF AIR CUSHION VEHICLES				
Configuration	1	2	3	4
R, D, T&E	7, 150	7, 150	7, 150	7, 150
Initial investment cost per vehicle	246, 450	124, 850	150, 150	89, 350
Maintenance costs	\$ 119, 700	58, 900	71, 500	41, 100
Fuel costs	\$ 68, 400	75, 800	34, 800	35, 200
Personnel costs	\$ 28, 600	28, 600	28, 600	28, 600
Attrition costs	\$ 24, 600	12, 500	15, 000	8, 900
Operating cost over vehicle life	\$ 241, 300	175, 800	149, 900	113, 800

CHAPTER IV

COST/EFFECTIVENESS COMPARISON

4.1 COST/EFFECTIVENESS MODEL

In this chapter, the optimized air-cushioned off-road logistic vehicle developed in Chapter II is compared with other vehicles being used, or proposed for use, in the same role. By comparing the effectiveness of each vehicle type to carry out the off-road logistics mission, together with the total costs involved in carrying out the mission, a measure of relative cost/effectiveness can be obtained. While this result cannot be the sole criterion in determining which vehicle to use in this role, it does provide an indication of the costs of superior performance. (At this point, it can only be assumed that improved mission performance is accompanied by increased costs.)

The method applied in the cost/effectiveness comparison is the determination of speed, fuel consumption, engineering support requirements, and total costs with which each of the vehicle types considered can carry out an assumed off-road logistics mission. The basic framework of the off-road logistics mission is the assumed mission environment defined in Chapter I and given in Table 1. As previously discussed (Section 1.3), the assumed mission environment is a combination of anticipated environmental situations which together make up the operational environment of the assumed mission. The percentages of total mission mileage assigned to each environmental situation are based on world-wide operations rather than on any specific area of operations. The relationship between the assumed mission environment and some commonly used environment categories has been previously given (see Table 2).

Within the framework of the assumed mission environment, the assumed mission simulates the logistics requirement for a division of the type field army, in the combat zone. This mission is similar to that discussed in U. S. Army Transportation Combat Development Group Project TCCD 61-83(SP), "Modernization of the Field Army Transport Service Through Employment of AC-1 and HC-1 Aircraft". (Reference 2)

For each combat zone division of the type field army, the following daily requirements are set forth in FM 101-10: (Reference 3)

Per division per day--short tons

	Class	I	II & IV	III	V	Total
Enters combat zone		98	147	231	203	679
Moved to army forward supply points		76	102	130	199	507
Moved to division area		58	66	50	195	369

Average distances (flying distances) are 100-150 miles from the rear boundary of the combat zone to the army forward supply points, and 50 miles from the army forward supply points to division supply points. Shorter range distribution operations within the division area will also be considered. Road distances (and off-road route distances) are assumed to be 50 per cent greater than flying distances.

In order to simplify the comparison, attention will be concentrated on the distribution of supplies forward from the army forward supply points. The basic range considered for all the vehicles is 100 miles, corresponding to 40 route miles each way after allowance for terminal operations, contingencies and reserve (total 20 per cent). Fuel mileage is based on 50 miles out (loaded) and 50 miles return (empty). The corresponding flying route mileage is 28 air miles.

All vehicles will be compared on the basis of this 100-mile range; then modifications will be incorporated to include vehicle ranges of 25, 50, and 250 miles, corresponding to surface route distances of 10, 20, and 100 miles and flying route distances of 7, 14, and 70 air miles.

The cost/effectiveness comparison will be based on the assumption of a single vehicle type providing the entire logistics support requirement. Although some of the off-road logistic vehicles (including the ACV) are not specifically designed for bulk POL delivery, it is assumed that class III supply delivered into the division area will include varying proportions of bulk and packaged POL, and that each vehicle type has the capability for handling these either in drums or in collapsible tanks.

For the basic comparison (assumed mission environment as in Section 1.3, supply requirements as given above, and vehicle operating range of 100 miles (distance forward equals 40 miles - road and off-road; 28 miles - air)), the following questions can be answered:

1. How many vehicles are needed?
2. What is the average speed?
3. How much fuel is consumed?
4. How much engineer support is needed (within the assumed environment)?
5. What are the direct costs associated with the vehicle system?

Effects of variations in range, number of hours per day of operation, and number of days over which to amortize engineer support costs will be considered in the final section. Variations in the assumed operating environment will be considered in the next chapter of the study.

Within the mission framework outlined above, the cost/effectiveness of the off-road ACV will be compared with that of the other vehicles being used, and proposed for use, in the mission. The contract requires consideration of vehicles such as the M135 truck, the GOER, the Musk Ox, the M52/M127 truck tractor-semitrailer combination, and the Chinook helicopter (HC-1B, now CH-47A). Characteristics of these vehicles are given in the next section.

4.2 VEHICLE PERFORMANCE AND COST DATA

This section contains performance and cost data on a number of vehicles being used, or proposed for use, in the off-road logistics mission. These data, together with the design performance and cost parameters of the off-road ACV developed in Chapters II and III, are primary inputs to the cost/effectiveness comparison. The method of the cost/effectiveness comparison was described in the preceding section, and the development will be carried out in the next section.

The contract work statement calls for consideration of vehicles "such as the GOER, Musk Ox, and M135 (2-1/2-ton truck)". During the development of the Plan for Performance, it was considered desirable to include the M52/M127 truck tractor-semitrailer combination and the HC-1B Chinook helicopter (now CH-47A). After review of available data, it was considered advantageous to substitute the Nodwell Transporter RN-110 for the Musk Ox. The Nodwell Transporter is also a

low-ground-pressure tracked vehicle, of 5.5 tons payload, more nearly the payload class of the other vehicles than the 20-ton payload Musk Ox. The Nodwell Transporter has been extensively tested in environmental operations. The M54 5-ton truck was added to fill out the analysis.

The vehicles to be compared for cost/effectiveness in the assumed off-road logistics mission defined in Section 4.1 are therefore:

1. M135 2-1/2-ton truck
2. M54 5-ton truck
3. XM520 5-ton GOER
4. XM437 15-ton GOER
5. M52/M127 truck tractor-semitrailer (12-ton payload)
6. Nodwell Transporter RN-110 (5.5-ton payload)
7. CH-47A Chinook helicopter (formerly HC-1B), payload 3-tons
8. Off-road ACV (without wheels), payloads 4.9, 4.3 tons
9. Off-road ACV (with wheels), payloads 4.6, 4.3 tons
10. Landrover/Gemini type vehicles.

Design and performance data for the optimized off-road ACV's were developed in Chapter II. These data are given in Tables 13 through 16. Cost data for the optimized off-road ACV were developed in Chapter III and are summarized in Table 18.

Design and performance data for the other vehicles are taken from Project WHEELTRACK, (Reference 29), from TCCD 61-83(SP), from reports of environmental operations, and from other technical materials. Design and performance data are summarized in Tables 19 through 25.

Cost data, including first cost, anticipated useful life, crew requirements, and maintenance requirements, are given in Table 26. The cost data were obtained from the Aeronutronic LOTS analysis, from the Stanford Research Institute Logistic System Study, from TRECOM, and from vehicle manufacturers (References 16, 41, and 42).

The following notes provide data supplementary to that in the tables.

NODWELL TRANSPORTER RN110

The Nodwell Transporter is one of a series of low-ground-pressure tracked vehicles developed for use in muskeg areas. It has been extensively used by oil companies engaged in exploration and drilling operations in northern Canada.

TABLE 19
NODWELL TRANSPORTER RN 110

Payload	11, 000 pounds
Gross Weight	21, 600 pounds (bridge class II)
Width	107 inches
Height	96 inches
Length	232 inches
Cargo Space	84 x 144 inches
Gradability	60% forward, 30% side
Ground Clearance	16 inches
Ground Pressure	2 psi @ zero penetration
Engine	186 hp, Ford V-8 industrial, 292 cubic inches
Fuel Capacity	45 gallons, motor gasoline
Cruising Range	60 miles
Floatability	nonfloating; fording depth, 36 inches; demonstrated fording to 43 inches

Remarks: 1) Top speed, 15 mph; TC Board recommends increase to 25 mph with new transmission.

2) Larger fuel tank (80 gallons) recommended by TC Board

3) Excellent mobility in snow and mud, including gradients to 40 per cent with load.

TABLE 20
M52/M127 TRUCK TRACTOR-SEMITRAILER

Payload	24, 400 pounds
Gross Weight	56, 500 pounds (class 24)
Width	97 inches
Height	109 inches
Length	524 inches (combination)
Cargo Space	88 x 335 inches
Gradability	65%
Ground Clearance	11.4 inches (14 inches with larger tires)
Ground Pressure	13 to 20 psi (9-17 psi with larger tires)
Engine	196 hp net (gasoline)
Fuel Capacity	110 gallons
Cruising Range	275 miles
Floatibility	nonfloating; fording depth, 30 inches

Remarks: 1) Vehicle not intended for general cross-country operations.

2) Line haul uses semitrailer shuttle service.

TABLE 21
GOER VEHICLES, 15-TON PAYLOAD AND 5-TON PAYLOAD

	XM 437 (Class 33)	XM 520 (Class 13)
Payload, pounds	30, 000	10, 000
Gross Weight, pounds	65, 800	26, 200
Width, inches	116	108
Height, inches	122 (reducible to 106)	120
Length, inches	434	314
Cargo Space, inches	104 x 156	98 x 150, but forward 67 only 62 wide
Gradability, percent	60 (much less on side slopes)	60
Ground Clearance, inches	Under chassis, 30 at axles, 30	Under chassis, 22; at axles, 21
Ground Pressure, psi	17	12
Engine	V-8 274-hp diesel	6 cylinder 93 hp net 110 hp
Fuel Capacity, gallons	157 diesel	40
Cruising Range, miles	300	160
Floatability	Floatable speed, avg. 3.3 mph	Prototype nonfloatable; fording depth, 42 inches Developed 8-ton GOER is floatable

Remarks: 1) Payload may be space-limited within small cargo compartment.

2) Developed models may have better side-slope capability.

TABLE 22
M35/M135 TRUCK, 6x6, 2-1/2-TON PAYLOAD

Payload	5,400 pounds
Gross Weight	18,200 pounds (class 9)
Width	96 inches
Height	111 inches
Length	275 inches (w/winch)
Cargo Space	88 x 147 inches
Gradability	64%
Ground Clearance	13 inches at axles, 18 inches between
Ground Pressure	8-14 psi for soft ground
Engine	146 hp, gasoline (127 hp net)
Fuel Capacity	50 gallons
Cruising Range	250 miles
Floatability	none
Remarks: M34, M35, M135 have generally same characteristics (M135 has automatic transmission, slightly greater fuel consumption).	

TABLE 23
M54 TRUCK, 6x6, 5-TON PAYLOAD

Payload	10,400 pounds
Gross Weight	32,200 pounds (class 15)
Width	97 inches
Height	116 inches
Length	310 inches
Cargo Space	88 x 168 inches
Gradability	60%
Ground Clearance	11.5 inches
Ground Pressure	12 to 22 psi
Engine	196 hp (gasoline) net
Fuel Capacity	78 gallons
Cruising Range	195 miles
Floatability	none

TABLE 24
CH-47A HELICOPTER (HC-1B)

Payload	Nominal 6,000 pounds	(capacity 18,000 pounds)
Gross Weight	25,700 pounds	
Width	fuselage	rotor diameter 59 feet
Height		
Length		
	12.4 feet - side pads	
	18.6 feet - rear rotor hub	
	51 feet	
Cargo Space	30 ft. long x 7 ft. 6 in. wide x 6 ft. 6 in. high (rear load)	
Gradability	not applicable	
Ground Clearance	not applicable	
Ground Pressure	not applicable	
Engine	2-Lycoming T55-L-5 @ 1850 SHP normal rating each	
Fuel Capacity	630 gallons, JP-4	
Cruising Range	230 miles (200 nautical miles)	
Floatability	floatable, but not applicable	
Remarks: 1) Range may be greatly extended for ferry mission.		
2) Rated cruise speed, 130 knots (150-mile-per-hour); block speed over 50-mile radius (58-s. mile radius) assumed to be 95 kts (110 mph).		

TABLE 25
LANDROVER/GEMINI TYPE VEHICLES

Payload	2,000 pounds
Gross Weight	8,485 pounds
Width	107 inches
Height	84 inches
Length	318 inches
Cargo Space	184 cubic feet
Gradability	60% (with jet assist)
Ground Clearance (max.)	24 inches
Ground Pressure	1/2 psi (with air cushion)
Engine	280 hp Corvette
Fuel Capacity	650 pounds
Cruising Range	dependent on surface
Floatability	yes

Remarks: None

TABLE 26 VEHICLE COST DATA								
Costing Parameters	M35/M135	M54	XM520	XM437	RN110	M52/M127	Helicopter CH 47A (HC-1B)	Cost Data GEMINI
Estimated vehicle cost	7,500	15,000	8,500	27,500	14,500	18,000	1,400,000	25,000
Operating life in mission environment	6667 hr.	6667 hr.	10,000 hr.	10,000 hr.	10,000 hr.	6667 hr.	10,000 hr.	10,000 hr.
Amortized cost per 20-hr. day	\$22.5	\$45.0	\$17.0	\$55.0	\$29.0	\$54.0	4 flying hours \$560	50.00
* Estimated maintenance cost (over vehicle life)	100 %	100 %	100 %	100 %	125 %	100 %	\$200/hr.	100 per cent
Maintenance cost per 20 hr. day	\$22.5	\$45.0	\$17.0	\$55.0	\$36.0	\$54.0	4 flying hours \$800	50.00
Number in crew	2	2	2	2	2	2	3	2 (1 each for 2-shift operation)
add 25% to amortized and maint. costs to cover equal number extra semi- trailers.								
* Estimated maintenance costs over life of the vehicle, except helicopter maintenance costs per hour from Reference 61.								

The ability of the Nodwell transporter to operate in snow, mud, clay, rocky soil, and muskeg has made it attractive for possible military applications. Performance characteristics of the vehicle are given in Table 19. Of particular interest is the low pressure (2 psi at zero penetration), which provides much of the mobility advantage.

The Nodwell RN110 has been tested in OPERATION WILLOW FREEZE, Reference 43, and in OPERATION SWAMP FOX, Reference 44. Other arctic and desert mobility tests have also been carried out, References 45, 46, and 47.

The least attractive features of the Nodwell Transporter RN110 as a military logistics vehicle are: nonfloatability, low road speed, and short cruising range. This vehicle can operate in almost any terrain except open water, but its maximum fording depth is 36 inches. At present, top speed is limited to about 15 miles per hour. The U. S. Army Transportation Board has recommended that the transmission gearing be changed to allow a road speed of 25 miles per hour. It is assumed that this modification could be successfully accomplished without compromising other capabilities. (A newer version of the RN110, with a diesel engine and a road speed of 25 mph was tested in Project WHEELTRACK, Reference 29.) Present cruising range of the vehicle is only 60 miles, with a 45-gallon fuel capacity. The Transportation Board has recommended that the fuel capacity be increased to 80 gallons, which would increase cruise range to 100 miles.

For the cost/effectiveness analysis, the Nodwell Transporter RN110 is assumed to have mobility capability in every segment of the assumed mission environment except river crossing, where bridging or a ferry would be required. Performance in the assumed mission environment is given in Table 28, based on test data and evaluation contained in References 43, 44, 45, 46, 47, and 48. It has been assumed that the top speed has been increased to 25 miles per hour by transmission modification, and that the range has been increased to 100 miles by increasing fuel capacity. The approximate gross weight would then be 22,000 pounds, with a payload of 11,000 pounds.

Larger versions of the Nodwell Transporter, with 25,000-pound payload capacity, have been used by oil companies. The Musk-Ox is a similar low-pressure tracked vehicle, of 40,000 pound payload, having articulated steering and equivalent performance to that of the Nodwell

Transporters. The excellent performance of these vehicles in snow, mud, and muskeg, as well as over rough terrains, makes them attractive candidates for the Army off-road logistics mission.

M52/M127 Truck Tractor-Semitrailer

The M52/M127 truck tractor-semitrailer combination provides the backbone of the Army motor transport system. Its use in line-haul transport is enhanced by adaptability to relay operations, wherein the tractors can be changed at regular time or distance intervals. Thus continuous forward movement of loaded semitrailers can be carried out, and the tractors can be utilized without idleness during loading and unloading operations. Its rated payload capacity is 12 tons.

The M52/M127 tractor-semitrailer configuration is not adaptable to extensive operation on unprepared routes because of its size and the unpowered rear axles on the semitrailer. Nevertheless, its superior performance and economy in line-haul operations encourages consideration of extending its operational environment. Tire modifications have been made so as to provide added capability in desert areas, Reference 49. Characteristics of the M52/M127 combination are given in Table 20.

The inclusion of the M52/M127 in the present analysis recognizes the limitations of operation in the off-road environment. Engineer support sufficient to provide capability within the assumed mission environment is included in the analysis.

Performance in the assumed mission environment is given in Table 38, based on test data and evaluation contained in References 49 and 50 and on notes on tests performed with "all-terrain" tires. In the analysis, credit is given for use of desert tires and "all-terrain" tires in appropriate environment segments.

M35, M135, M54 Trucks

The "work horse" of the Transportation Light Truck Company and most common cargo carrier in the inventory of the Army, is the 2-1/2-ton truck. The long development series of the 6 x 6 all-wheel-drive truck in 2-1/2-ton and 5-ton payload categories has produced a variety of models, all of the same basic design. Present models of the M35

series (and the similar M34) provide on-road and limited off-road transport of personnel and cargo, and a large number of other functions. The M135 has the same configuration, but incorporates an automatic transmission. In the 5-ton category, the M54 series has nearly the same performance characteristics, with double the payload capacity in off-road operations. Characteristics of the M35 6 x 6 truck are given in Table 22, and may be assumed to represent the M34 and M135 trucks, as well. Characteristics of the M54 are given in Table 23.

The performance of these vehicles in the assumed mission environment is given in Tables 30 and 31, and Tables 32 and 33. These performance figures are based on material in test data and evaluation from References 49, 50, 51, 52, 53, 54, 55, 56, and 57.

All these data are based on the use of the present spark-ignition (gasoline) engines. The Army is developing multifuel engines (compression ignition) which will burn diesel fuel, gasoline, JP-4, marine fuels, and kerosene. Fuel economy is the primary goal of these developments, with anticipated improvements up to 40 per cent in miles per gallon (based on diesel fuel). This averages about 25 per cent improvement in pounds of fuel per mile (the difference due to the higher density of diesel fuels). Accordingly, the fuel consumption given in Tables 31 and 33 can be reduced by 25 per cent if multifuel engines operating on diesel fuel are installed. Vehicle weights will increase slightly, while vehicle performance and mobility will be essentially the same.

GOER Vehicles XM520, XM437

GOER vehicles were developed by the Army to provide increased mobility for combat support missions. The GOER concept utilizes commercial earthmover-type design and construction. Among the features are articulated steering, large unsprung wheels, exoskeletal body construction, and swimmability.

The original development vehicles included the XM520, a 5-ton rated payload vehicle not having the swimmability feature; the XM437, a 15-ton payload cargo carrier; and the XM438, a 5,000-gallon tanker. The XM-437 has now been developed as a 16-ton cargo carrier; and a further development of the XM520 type is the XM520E1, of 8 tons payload capacity and with swimming capability.

While GOER vehicles have shown significant improvement in off-road mobility over conventional trucks, several deficiencies have been revealed. First, their handling at high speeds in on-road operations (greater than 30 miles per hour) is deficient relative to that of conventional trucks. Secondly, the payload compartments are small relative to the large payload (weight) capacity, so that only very dense cargoes can be loaded to vehicle rated payload capacity. Thirdly, the exoskeletal construction and swimmability features result in high nondrop body sides, such that loading and unloading of heavy items is very difficult.

Characteristics of the XM437 and XM520 GOER vehicles are given in Table 21. Performance of these vehicles in the assumed mission environment is given in Tables 34 and 36 and summarized in Tables 35 and 37, based on test results and evaluation in References 50, 56, 58, and 59. The original XM520 (nonswimming) model of the 5-ton GOER has been used in the analysis.

CH-47A Helicopter (Chinook)

As an alternate to the surface mobility systems, the CH-47A Helicopter (Chinook) has been included in the analysis. The CH-47A (formerly designated HC-1B) is programmed to replace the H-37 in the Transportation Medium Helicopter Company. Characteristics of the CH-47A are given in Table 24. Note that performance figures have been changed from nautical miles to statute miles for comparison with other systems.

The nominal payload of the CH-47A is 3 tons; but at ranges of 100 air miles and less, this can be increased. Assuming a fixed maneuvering time in each flight leg, average block speed decreases as the range is decreased.

The performance of the CH-47A in the assumed mission environment is given in Table 40 and summarized in Table 41, based on data in References 2, 60, and 61.

LANDROVER/GEMINI-TYPE VEHICLES

Although not meeting the requirements of this study as far as payload is concerned, and therefore not considered in the model, vehicles of the Landrover/Gemini type have been studied. These studies, however, have been limited due to the lack of detailed information on their

performance and operational characteristics. Nevertheless, their capability has been assessed in a manner similar to that used for the current conventional off-road vehicles. As the full converted Landrover with air cushion assist embodies, by definition, a relatively heavy structure in keeping with its previous commitments, it has been assumed that a true U. S. Army off-road vehicle designed in this manner would follow the Gemini concept. Accordingly, the characteristics outlined in the Hawker Siddeley Canada Ltd. (Engineering Division) brochure dated September 1962 and supplemented by information supplied by USATRECOM has been used (Table 25).

Although this type of vehicle is in the development stage, there is sufficient evidence to show that, apart from payload limitations in the sizes under development, this configuration probably offers a truer off-road capability than any other concept so far evaluated. With the air cushion assist, it is possible for the vehicle to present a ground pressure that is one quarter of the ground pressure exerted by the Nodwell transporter--already well known for its off-road capability.

Supporting the development of this vehicle is the experience demonstrated by the Vickers Landrover conversion. This vehicle, although using a heavy structure, has been in operation for over 12 months over a wide variety of off-road terrains. The performance of this vehicle has been adequately demonstrated and is believed to provide some insight into the anticipated performance expected from vehicles of the GEMINI type.

Of the many missions that could be studied, the following serves as an example of GEMINI capability. Such a mission could possibly arise in some of the relatively undeveloped areas of Southeast Asia. The figures given are based on one self-supporting vehicle. It is expected that two or three vehicles might make the reconnaissance at the same time for mutual support. For this mission, an overload of fuel stored in jerricans is possible because the initial portion of the journey is by road. (Data from manufacturer's brochure)

Mission: Reconnaissance patrol of an area of rough and swampy terrain separated from base by 250 miles of dirt road.

Combat Team: 5 men with combat equipment, food, water, and cooking fuel for 10 days.

Ammunition: 6,000 rounds 7.6 mm
 80 M26 hand grenades
 10 M72 rocket grenades

Fuel: Normal fuel and seven 5-gal. jerricans extra.

Assuming the above conditions, the GEMINI could travel at 40 miles per hour on the dirt road. Before leaving the road, the fuel would be replenished from the seven 5-gallon jerricans. The GEMINI could then travel 130 miles at 10 miles per hour over rough terrain, using its amphibious capability for crossing rivers or small lakes. Allowing an extra 5 miles of travel over swamp at 10 miles per hour, using the ground cushion, the GEMINI would still have sufficient range to return to base with full ammunition load, 3 days' unconsumed allowance of food and water, and 6 gallons reserve of fuel, which would be sufficient for an extra 45 miles of dirt-road travel.

4.3 COST/EFFECTIVENESS DEVELOPMENT

The development of cost/effectiveness follows the procedures set forth in Section 4.1. Mobility and performance characteristics for the optimized ACV off-road logistic vehicle were developed in Chapter II. Cost parameters for the ACV were developed in Chapter III. Basic performance parameters and costs for some competing and complementary vehicles (present and proposed) in the off-road logistics mission were assembled in Section 4.2.

The basis of the cost/effectiveness comparison is the analysis of vehicle mobility and performance. Cost parameters associated with each system can then be tabulated and the resulting ratios compared.

For the first approximation to system mobility and performance, these parameters are all referenced to the assumed mission environment developed in Chapter I (Table 1). While this assumed environment could be modified to simulate a specific environment region, such as desert (see Table 2), such refinements tend to obscure the more basic system performance differences. For similar reasons, only a single mission range is used in the first approximation, with effects of range variation to be applied later. A range of 100 miles has been chosen for the first comparison, only because it allows percentages to be converted directly to miles.

TABLE 27
"SIGNIFICANT" SURFACE PARAMETERS

Route Segment	Significant Surface Parameters
1. Graded rough road with gradients less than 15 per cent _____	hard surface, good traction
2. Ungraded open grassland, obstacles less than 3 feet, rolling grades less than 30 per cent _____	soft surface, mixed cohesive and frictional soils
3. River crossing, banks 30-50 per cent, current 3 knots _____	soft surface, cohesive (steep slope) and water
4. Uncleared forest, trees spaced 15-30 feet, undergrowth to 2 feet, occasional stumps up to 3 feet _____	mixed surface, rough, (mostly "hard", frictional soils)
5. Swamp area, scattered vegetation, only occasional obstacles over 2 feet, space between tree roots over 15 feet _____	soft surface, cohesive and sticky, some water
6. Two-lane surfaced highway, soft shoulders, bank less than 30 per cent _____	hard surface, good traction
7. Open desert with some dunes, gradients on dunes up to 30 per cent _____	soft surface, frictional soil, some steep slopes
8. Dry-stream valley, twisting floor bed with rocks up to 2 feet, rocky banks _____	hard surface, rough (steep slopes)
9. Rain-soaked, graded dirt road, wheel ruts up to 2 feet deep, obstacles require periodic leaving road and returning up and down grades 30 per cent _____	soft surface, cohesive

TABLE 28 NODWELL TRANSPORTER RN-110, PAYLOAD 5.5 TONS				
Route Segment	Go- No Go	Avg. Speed (mph)	Fuel Consumption (lb/mi)	Remarks
1. Graded rough road with gradients less than 15 per cent	Go	~15	~3	Improved type
2. Ungraded open grassland, obstacles less than 3 feet, rolling grades less than 30 per cent	Go	~8	4.0	
3. River crossing, banks 30-50 per cent, current 3 knots	No	(8)	(4)	Nonfloating, bridging required
4. Uncleared forest, trees spaced 15-30 feet, undergrowth to 2 feet, occasional stumps up to 3 feet	Go	~4	~8	
5. Swamp area, scattered vegetation, only occasional obstacles over 2 feet, space between tree roots over 15 feet	Go	~4	~8	
6. Two-lane surfaced highway, soft shoulders, bank less than 30 per cent	Go	~20	~2.5	Improved type, currently limited to 15 mph by gearing.
7. Open desert with some dunes, gradients on dunes up to 30 per cent	Go	7.5	4.5	75% sand plains, 25% dunes
8. Dry-stream valley, twisting floor bed with rocks up to 2 feet, rocky banks	Go	~4	~8	
9. Rain-soaked, graded dirt road, wheel ruts up to 2 feet deep, obstacles require periodic leaving road and returning up and down grades 30 per cent	Go	~5	~6	

TABLE 29
NODWELL TRANSPORTER RN-110, PAYLOAD 5.5 TONS

Route Segment	Mileage (mi) or (%)	Speed (mph)	Time (hr)	Fuel Consumption (lb/mi)	Fuel Used (lb)
1	15	15	1.00	3	45
2	20	8	2.50	4	80
3*	5	(8)	.62	(4)	20
4	10	4	2.50	8	80
5	10	4	2.50	8	80
6	25	20	1.25	2.5	63
7	5	7.5	.67	4.5	22
8	5	4	1.25	8	40
9	5	5	<u>1.00</u>	6	<u>30</u>
				13.29 hours	460 lb

For 100 miles range, route mileage is 40.

Average speed = 7.5 mph

Fuel consumption = 4.6 lb/mi

Fuel consumption per ton delivered (one way) = 84 lb/ton

Fuel consumption per ton forward per mile forward = 2.1 lb/ton/
mile forward

* Engineer support:

Segment 3, river crossing, 1600-ft. bridging (one way), or
ferry, with 1.7 miles access road (pioneer combat road,
two-lane).

TABLE 30
M35 M135 TRUCK, 6x6, PAYLOAD 2-1/2 TONS

Route Segment	Go- No Go	Avg. Speed (mph)	Fuel Consumption (lb/mi)	Remarks
1. Graded rough road with gradients less than 15 per cent	Go	20	1.3	
2. Ungraded open grassland, obstacles less than 3 feet, rolling grades less than 30 per cent	Go	~8	~2.5	
3. River crossing, banks 30-50 per cent, current 3 knots	No	(12)	(1.8)	Nonfloating bridge or ferry required
4. Uncleared forest, trees spaced 15-30 feet, undergrowth to 2 feet, occasional stumps up to 3 feet	Go	~3	~5	
5. Swamp area, scattered vegetation, only occasional obstacles over 2 feet, space between tree roots over 15 feet	No	(15)	(1.6)	No traction, road and fill required (1.5 distance)
6. Two-lane surfaced highway, soft shoulders, bank less than 30 per cent	Go	30+	0.95	
7. Open desert with some dunes, gradients on dunes up to 30 per cent	Go	10	~2.0	With single desert tires
8. Dry-stream valley, twisting floor bed with rocks up to 2 feet, rocky banks	Marginal	~3	~5	Some engineer support may be required to fill, or to clear lane
9. Rain-soaked, graded dirt road, wheel ruts up to 2 feet deep, obstacles require periodic leaving road and returning up and down grades 30 per cent	No	(~2-)	(~8)	Assistance via winch required - assumed to be available

Note: Total fuel economy of multi fuel engine (using diesel fuel) has been assumed to be 25% better than gasoline engine

TABLE 31
M35 & M135 TRUCK 6x6 PAYLOAD 2-1/2 TONS

Route Segment	Mileage (mi)or(%)	Speed (mph)	Time (hr)	Fuel Consumption (lb/mi)	Fuel Used ** (lb)
1	15	20	.75	1.3	20
2	20	8	2.50	2.5	50
3 *	5	(12)	.42	(1.8)	9
4	10	3	3.33	5	50
5 *	10 (x1.5)	(15)	1.00	(1.6)	24
6	25	30+	.83	0.95	24
7	5	10	.50	2.0	10
8	5	3	1.67	5	25
9 *	<u>5</u>	(~2-)	<u>2.50</u>	(~8)	<u>40</u>
			13.50		252

For 100 miles range, route mileage is 40.

Average speed = 7.4 mph

Fuel consumption = 2.5 lb/mi

Fuel consumption per ton delivered (one way) = 100 lb/ton

Fuel consumption per ton forward per mile forward = 2.5 lb/ton/mi fwd

* Engineer support: over 40 route miles, support required on segments 3, 5, 9, and maybe 8

Segment 3, river crossing: 1600 ft one-way bridging & 1.7 miles access road, two lane, earth

Segment 5, swamp: 6 mi. rough road and fill (length 1.5 route dis.)

Segment 9, muddy, rutted road: winching or tow (assumed available)

Segment 8, stream bed: occasional fill or rock clearing

** For multifuel engine using diesel oil, use .75 of fuel consumption given here.

TABLE 32 M54 TRUCK, 6x6, PAYLOAD 5 TONS				
Route Segment	Go- No Go	Avg. Speed (mph)	Fuel Consumption (lb/mi) Estimated	Remarks
1. Graded rough road with gradients less than 15 per cent	Go	20	2.0	
2. Ungraded open grassland, obstacles less than 3 feet, rolling grades less than 30 per cent	Go	~8	4.0	
3. River crossing, banks 30-50 per cent, current 3 knots	No	(12)	(2.8)	Nonfloating bridge or ferry (required)
4. Uncleared forest, trees spaced 15-30 feet, undergrowth to 2 feet, occasional stumps up to 3 feet	Go	~3	8	
5. Swamp area, scattered vegetation, only occasional obstacles over 2 feet, space between tree roots over 15 feet	No	(15)	(2.4)	No traction - road and fill required (~1.5 distance)
6. Two-lane surfaced highway, soft shoulders, bank less than 30 per cent	Go	30+	1.7	
7. Open desert with some dunes, gradients on dunes up to 30 per cent	Go	10	3	
8. Dry stream valley, twisting floor bed with rocks up to 2 feet, rocky banks	Marginal Go	~3	8	Some engine support may be required to fill, or to clear lane
9. Rain soaked, graded dirt road, wheel ruts up to 2 feet deep, obstacles require periodic leaving road and returning up and down grades 30 per cent	No	(~2-)	(~12)	Assistance via winch or tow, assumed to be available

TABLE 33
M54 TRUCK, 6x6, PAYLOAD 5 TONS

Route Segment	Mileage (mi) or (%)	Speed (mph)	Time (hrs)	Fuel Consumption (lb/mi) (estimated)	Fuel Used (lb)
1	15	20	.75	2.0	30
2	20	8	2.50	4	80
3*	5	(12)	.42	(2.8)	12
4	10	3	3.33	8	80
5*	10 (x1.5)	(15)	1.00	(2.4)	36
6	25	30+	.83	1.7	43
7	5	10	.50	3	15
8	5	3	1.67	8	40
9*	5	(~2-)	2.50	(~12)	60
			13.50 hours		396 lb

For 100 miles range, route mileage is 40.

Average speed = 7.4 mph

Fuel consumption = 4.0 lb/mi

Fuel consumption per ton delivered (one way) = 79 lb/ton

Fuel consumption per ton forward per mile forward = 2.0 lb/ton/
mile forward

* Engineer support: (40 route miles)

Segment 3, river crossing: 1600 ft. one-way bridging + 1.7 miles
access road 2 lane earth

Segment 5, swamp: 6 miles rough road + fill (1.5 x route distance)

Segment 8, stream bed: occasional fill or rock clearing, assumed
available where needed

Segment 9, muddy rutted road, winching or tow (assumed available)

TABLE 34 GOER (XM520), PAYLOAD 5 TONS				
Route Segment	Go- No Go	Avg. Speed (mph)	Fuel Consumption (lb/mi) (estimated)	Remarks
1. Graded rough road with gradients less than 15 per cent	Go	17	~1.4	
2. Ungraded open grassland, obstacles less than 3 feet, rolling grades less than 30 per cent	Go	8	~2.5	
3. River crossing, banks 30-50 per cent, current 3 knots	No	(12)	(~1.8)	Bridge or ferry req'd. Development model nonfloating; fords 42 inches
4. Uncleared forest, trees spaced 15-30 feet, undergrowth to 2 feet, occasional stumps up to 3 feet	Go	4	~3.5	
5. Swamp area, scattered vegetation, only occasional obstacles over 2 feet, space between tree roots over 15 feet	No	(12)	~(1.8)	~(> 2 ft) bypass of deep swamp required (use road 1.5 x distance)
6. Two-lane surfaced highway, soft shoulders, bank less than 30 per cent	Go	~22	~1.5	
7. Open desert with some dunes, gradients on dunes up to 30 per cent	Go	~10	~2	
8. Dry-stream valley, twisting floor bed with rocks up to 2 feet, rocky banks	Go	4	~3.5	
9. Rain-soaked, graded dirt road, wheel ruts up to 2 feet deep, obstacles require periodic leaving road and returning up and down grades 30 per cent	Go	2	~6	

TABLE 35 GOER (SM520), PAYLOAD 5 TONS (SEE NOTE)					
Route Segment	Mileage (mi) or (%)	Speed (mph)	Time (hrs)	Fuel Consumption (lb/mi) (estimated)	Fuel Used (lb)
1.	15	17	.88	~1.4	21
2.	20	8	2.50	~2.5	50
3.*	5	(12)	.42	~(1.8)	9
4.	10	4	2.50	~3.5	35
5.*	10(x1.5)	12	1.25	~(1.8)	27
6.	25	~22	1.14	~1.5	38
7.	5	~10	.50	~2	10
8.	5	4	1.25	~3.5	17
9.	5	2	2.50	~6	30
	100 miles		12.94 hours		237 pounds (diesel) (estimate) **

For 100 miles range, route mileage is 40.
Average speed = 77

Fuel consumption = 2.6 lb/mi (diesel)
Fuel consumption per ton delivered (one way) = (58 lb/ton @ "avg" payload) See note.
(52 lb/ton @ max payload)

Fuel consumption per ton forward per mile forward = (1.4 @ "avg." payload)
(1.4 lb/ton/mile forward)

* Engineer support: route segment (5) swamp; bypass required ~1.5 route distance
(1.5)(.10)(40) = 6 miles rough road
(3) river crossing, bridging or ferry 1600 ft water gap, plus 1.7 miles access road (pioneer road - 2 lane)

** Add 10% to cover errors = 23; total 260 pounds

Note: In present configuration, payload is space limited for class I and class III cargoes to 4 tons; only with class V cargoes can 5 tons be carried, use "avg" payload 4.5 tons (from tests reported Reference 56).

TABLE 36 GOER (XM437), PAYLOAD 15 TONS				
Route Segment	Go- No Go	Avg. Speed (mph)	Fuel Consumption (lb/mi) (diesel)	Remarks
1. Graded rough road with gradients less than 15 per cent	Go	20	2.7	
2. Ungraded open grassland, obstacles less than 3 feet, rolling grades less than 30 per cent	Go	9	4	
3. River crossing, banks 30-50 per cent, current 3 knots	Go	3.5	~6	
4. Uncleared forest, trees spaced 15-30 feet, undergrowth to 2 feet, occasional stumps up to 3 feet	Go	4	5.5	
5. Swamp area, scattered vegetation, only occasional obstacles over 2 feet, space between tree roots over 15 feet	No	~(12)	~(3.5)	Can negotiate muskeg to 3 ft. deep at 1.5 mph. By pass of deeper swamp areas required (use road 1.5 x distance)
6. Two-lane surfaced highway, soft shoulders, bank less than 30 per cent	Go	25	2.9	
7. Open desert with some dunes, gradients on dunes up to 30 per cent	Go	~10	~4	2 mph in dune areas, good dune capability w. 4-wheel drive
8. Dry stream valley, twisting floor bed with rocks up to 2 feet, rocky banks	Go	4	5.5	
9. Rain soaked, graded dirt road, wheel ruts up to two feet deep, obstacles require periodic leaving road and returning up and down grades 30 per cent	marginal Go	2	~10	Poor side-slope capability in muddy areas (slips)

TABLE 37 GOER (XM437), PAYLOAD 15 TONS (SEE NOTE)					
Route Segment	Mileage (mi) or (%)	Speed (mph)	Time (hrs)	Fuel Consumption (lb/mi) (diesel)	Fuel Used (lb)
1.	15	20	.75	2.7	40
2.	20	9	2.22	4	80
3.	5	3.5	1.43	~6	30
4.	10	4	2.50	5.5	55
5.	10(x1.5)	~(12)	1.25	~(3.5)	53
6.	25	25	1.00	2.9	73
7.	5	~10	.50	~4	20
8.	5	4	1.25	5.5	27
9.	5	2	2.50	~10	50
	100 miles		13.40 hours		428 pounds (diesel)
For 100 miles range, route mileage is 40.					
Average speed 7.5 mph					
Fuel Consumption 4.3 lb/mi (diesel)					
Fuel consumption per ton delivered (one way) = (34 @ 12.5 ton "avg" payload) See note (28.0 lb/ton at full payload)					
Fuel consumption per ton forward per mile forward = (85 @ "avg" payload) (71 lb/ton/mile forward)					
* Engineer support: route segment (5) swamp; bypass road required -- 1.5 route distance (1.5)(.10)(40) = 6 miles rough road					
Note: In present configuration XM437, payload is space-limited to 15 tons (class V), to less than 10 tons (other cargoes), use average 12.5 tons payload. (from tests reported in reference 56.)					

TABLE 38 M52/M127 TRUCK TRACTOR-SEMITRAILER, PAYLOAD 12 TONS				
Route Segment	Go- No Go	Avg. Speed (mph)	Fuel Consumption (lb/mi)	Remarks
1. Graded rough road with gradients less than 15 per cent	Go	15	3.3	
2. Ungraded open grassland, obstacles less than 3 feet, rolling grades less than 30 per cent	Go	~5	~6	With all-terrain tires
3. River crossing, banks 30-50 per cent, current 3 knots	No	(8)	(4.5)	Non-floating, bridging req'd
4. Uncleared forest, trees spaced 15-30 feet, undergrowth to 2 feet, occasional stumps up to 3 feet	No	(~10)	(4)	Not maneuverable, road required (unimproved)
5. Swamp area, scattered vegetation, only occasional obstacles over 2 feet, space between tree roots over 15 feet	No	(~10)	(4)	Non-floating, insufficient traction, road to circumvent (1.5 distance) + fill 20%.
6. Two-lane surfaced highway, soft shoulders, bank less than 30 per cent	Go	30-	2.3	Marginal on dunes @ 4 mph (add .25 distance) desert tires
7. Open desert with some dunes, gradients on dunes up to 30 per cent	Go	~9	~5	
8. Dry stream valley, twisting floor bed with rocks up to 2 feet, rocky banks	No	(~5)	(6)	Insufficient clearance, fill or clear route
9. Rain soaked, graded dirt road, wheel ruts up to two feet deep, obstacles require periodic leaving road and returning up and down grades 30 per cent	No	(~1.5)	(~12)	Tow required, all-terrain tires
Note: Credit for all-terrain and desert tires in appropriate environments. ref. 52, 53 notes on terra tip tests				

TABLE 39 M52/M127 TRUCK TRACTOR-SEMITRAILER, PAYLOAD 12 TONS					
Route Segment	Mileage (mi) or (%)	Speed (mph)	Time (hrs)	Fuel Consumption (lb/mi)	Fuel Used (lb)
1.	15	15	1.00	3.3	50
2.	20	5	4.00	6	120
3.*	5	(8)	.62	(4.5)	22
4.*	10	(~10)	1.00	(4)	40
5.*	10x(1.5) road distance	(~10)	4.50	(4)	60
6.	25	30-	.85	2.3	58
7.	5x1.25	9	.70	5	31
8.*	5	(~5)	1.00	(6)	30
9.*	5	(~1.5)	3.33	(~12)	60
	100 miles		14.00 hours		471 pounds
<p>For 100 miles range, route mileage is 40.</p> <p>Average speed 7.1 mph</p> <p>Fuel consumption 4.7 lb/mi</p> <p>Fuel consumption per ton delivered (one way) = 39 lb/ton</p> <p>Fuel consumption per ton forward per mile forward = 0.98 lb/ton/mile forward</p> <p>* Engineer support: (40 route miles), support required in segments 3, 4, 5, 8, 9</p> <p>Segment (3) river crossing 1600 ft. bridging one-way (or ferry) & 1.7 miles access rd. 2-lane earth</p> <p>(4) forest 4 miles pioneer road, clearing and grading</p> <p>(5) swamp 6 miles pioneer road and fill around swamp, length is route distance x 1.5 for relocation on dry ground</p> <p>(8) streambed 2 miles rough road, clear rocks and/or fill with dirt</p> <p>(9) muddy rutted road - tow required. (Towing tractor assumed to be available)</p>					
Note: Credit for all-terrain and desert tires where appropriate.					

TABLE 40 CH-47A HELICOPTER (HC-1B), PAYLOAD 3 TONS (4 TONS AT SHORT RANGES)				
Route Segment	Go- No Go	Avg. Speed (mph)	Avg. Fuel Consumption (lb/mi)	Remarks
1. Graded rough road with gradients less than 15 per cent 2. Ungraded open grassland, obstacles less than 3 feet, rolling grades less than 30 per cent 3. River crossing, banks 30-50 per cent, current 3 knots 4. Uncleared forest, trees spaced 15-30 feet, undergrowth to 2 feet, occasional stumps up to 3 feet 5. Swamp area, scattered vegetation, only occasional obstacles over 2 feet, space between tree roots over 15 feet 6. Two-lane surfaced highway, soft shoulders, bank less than 30 per cent 7. Open desert with some dunes, gradients on dunes up to 30 per cent 8. Dry stream valley, twisting floor bed with rocks up to 2 feet, rocky banks 9. Rain soaked, graded dirt road, wheel ruts up to two feet deep, obstacles require periodic leaving road and returning up and down grades 30 per cent	Assumed all-terrain capability (daylight hours)	Assumed 110 mph (~95 knots)	~ 950 pounds, @ 13.5 lb/mile	
Note: 100 mile road range corresponds 40 route miles ~28 air miles corresponds ~70 miles air range.				

TABLE 41 CH'47A-HELICOPTER (HC-1B), PAYLOAD 3 TONS (4 TONS AT SHORT RANGE)									
Route Segment	Mileage (mi) or (%)	Speed (mph)	Time (hrs)	Fuel Consumption (lb/mi)	Fuel Used (lb)				
1.	15	110 avg.	~.63 hours	13.5 lb/mi avg.	950 pounds				
2.	20								
3.	5								
4.	10								
5.	10	110 avg.	~.63 hours	13.5 lb/mi avg.	950 pounds				
6.	25								
7.	5								
8.	5								
9.	5	110 avg.	~.63 hours	13.5 lb/mi avg.	950 pounds				
100 miles (70 air miles)									
For 100 miles range, route mileage is 40. 70 miles air range route air mileage is 28 corresponding to above Average speed = 110 mph (assuming 5 minute maneuver time per leg) Fuel consumption = 13.5 lb/mi Fuel consumption per ton delivered (one way)= ~320 lb/ton (3 ton payload) Fuel consumption per ton forward per mile forward = 11.3 lb/ton/air mile forward 8.0 lb/ton/road mile forward Engineer support: Assumed none - (prepared landing space included in terminal area costs)									
Note: Helicopter 70 miles range equivalent to ground 100 miles range - all speeds in mph, all ranges in statute miles. At this range payload availability ~4 tons: ∴ fuel = 240 lb/ton = 8.5 lb/ton/air mile forward = 6 lb/ton/road mile forward									

TABLE 42 GEMINI, PAYLOAD 1 TON				
Route Segment	Go- No Go	Avg. Speed (mph)	Fuel Consumption (lb/mi)	Remarks
1. Graded rough road with gradients less than 15 per cent _____	Go	20	.8	
2. Ungraded open grassland, obstacles less than 3 feet, rolling grades less than 30 per cent —	Go	10	1.0	
3. River crossing, banks 30-50 per cent, current 3 knots _____	Go	10	27	On air cushion
4. Uncleared forest, trees spaced 15-30 feet, undergrowth to 2 feet, occasional stumps up to 3 feet _____	Go	4	2.5	
5. Swamp area, scattered vegetation, only occasional obstacles over 2 feet, space between tree roots over 15 feet _____	Go	10	15	Using partial air cushion and wheels
6. Two-lane surfaced highway, soft shoulders bank less than 30 per cent _____	Go	30+	.7	
7. Open desert with some dunes, gradients on dunes up to 30 per cent _____	Go	10	2.0	High rolling resistance
8. Dry stream valley, twisting floor bed with rocks up to 2 feet, rocky banks _____	Go	4	2.5	
9. Rain soaked, graded dirt road, wheel ruts up to 2 feet deep, obstacles require periodic leaving road and returning up and down grades 30 per cent _____	Go	5	50	Using air cushion and wheels
Note: Air cushion used only in segments 3, 5, and 9.				

TABLE 43
GEMINI, PAYLOAD 1 TON

Route Segment	Mileage (mi) or (%)	Speed (mph)	Time (hrs)	Fuel Consumption (lb/mi)	Fuel Used (lb)
1	15	20	.75	.8	12
2	20	10	2.00	1.0	20
3	5	10	.50	27	135
4	10	4	2.50	2.5	25
5	10	10	1.00	15	150
6	25	30+	.83	.7	18
7	5	10	.50	2.0	10
8	5	4	1.25	2.5	12
9	5	5	<u>1.00</u>	50	<u>250</u>
10.33 hours					632 pounds

For 100 miles range, route mileage is 40.

Average speed = 9.7 mph

Fuel consumption = 6.3 lb/mi.

Fuel consumption per ton delivered (one way) = 630 lb/ton

Fuel consumption per ton forward per mile forward = 15.8 lb/ton/mi.
forward

Engineer support: none required

Based on the assumed mission environment, then, each vehicle system is analyzed to determine the average speed and fuel consumption for 100 miles of operation within the assumed environment, carrying rated payload.

For environmental situations where the vehicle has no mobility, engineering support is assumed to have been provided, and speeds and fuel mileage applicable to the improved route (road built or bridging laid, etc.) have been used. The cost of the engineering support is listed on the performance chart, as an input to the cost analysis. Thus, each vehicle system is assumed to have capability for the entire mission, with engineering support as required.

Using the assumed mission outline, the mobility and performance of the system in each environmental situation have been listed in Tables 32 to 40, including notation of engineering support required in the "no-go" situations. The operating range of 100 miles is assumed to cover 40 cross-country route miles each way (this does, however, include existing road mileage). Twenty per cent of the mission mileage is assumed to be used in terminal areas, contingencies, and reserve. In order to simplify the analysis, this has been evenly divided among the environmental situations.

Vehicle mobility and performance data are taken from the materials referenced in Section 4.2. Data for the optimized off-road ACV are taken from Chapter II. Engineering support requirements are from Staff Officer's Field Manual FM 101-10. The calculations of average speeds and fuel consumption for each system are given in the supplementary tables accompanying Tables 28 to 40. (29 to 41)

Values for speeds and fuel consumption listed in the tables and supplementary sheets have been applied directly from environmental and other test operations reports, where available. In many cases, it has been necessary to separate factors found in the original data; i. e., fuel consumption data analysis for a given cross-country test often averages both the on-road and the off-road values. Care has been used in determining values, but no single value for operation in a specific environmental segment has the same degree of confidence or order of significance as the average values determined for the vehicle.

In order to assist the extrapolation of mobility parameters from test data, the route segments of the assumed mission environment have been further defined by the parameters having most significance for vehicle mobility. These parameters have been arbitrarily called "Significant" Surface Parameters, and are given in Table 27. "Significant" Surface Parameters include the material type and strength of the surface, as well as its geometry, depending on what factor is considered critical to vehicle operation. For example, in route segment 5, "swamp area", the "Significant" Surface Parameters are "soft surface, cohesive and sticky, some water". While the route segment (5) description also includes obstacles and tree roots, the critical factors for mobility are the stickiness and cohesiveness of soft surface materials, which may be combined with water on, or below the surface.

In this way, all the route segments of the assumed mission environment are further identified, and the analysis is thereby simplified. While it would be indeed advantageous to quantify the environment in terms of numerical parameters such as "average soil cone index", "coefficient of soil cohesion", "angle of friction" (between soil grains), and mean obstacle height and spacing, average gradient, etc., the test operations data are not sufficiently precise to justify these refinements in the cost/effectiveness comparison. Quantitative surface parameter factors were applied in the off-road ACV design development in Chapter II.

As a typical example of the mobility and performance analysis, Tables 28 and 29 present data and calculations for the Nodwell Transporter RN110. This vehicle is described in Table 19 in Section 4.2. Table 28 gives "go, no-go" segments, average speed (mph), and fuel consumption (lb/mile) for operation of the Nodwell Transporter in the assumed mission environment based on data in References 43, 44, 45, 46, 47, and 48. From reference to Table 28, it can be seen that this low-pressure tracked vehicle has excellent mobility, with capability in every route segment except 3, "river crossing". Since the vehicle is nonfloating, a bridge or ferry must be provided for negotiating this portion of the environment. The speed and fuel consumption values given in parentheses indicate operation with engineer support. (Improvements in the vehicle on-road speed, as suggested by the TC Board, are assumed to have been incorporated.) (See, for example, modified vehicle tested in Project WHEELTRACK, Reference 50.)

Average speed and fuel consumption for the Nodwell Transporter RN110 are calculated in Table 29. It can be seen that the average speed over the entire assumed mission environment is about 7.5 miles per hour, with a fuel consumption of 2.1 pounds-per-ton payload per mile forward (100 miles range less 20 per cent, divided by 2, equals 40 miles forward). Engineer support includes bridging or floating bridging (or ferry) covering 1,600 feet (40 feet per mile x 40 miles route, as per FM 101-10), and access roads (pioneer type) covering the remainder of the route segment (3), 5 per cent x 40 miles - 1,600 feet = 1.7 miles.

Performance and fuel consumption of the other vehicles in the assumed mission environment are given in Tables 30 to 40 and summarized in Tables 31 to 41.

The M35 and M135 trucks, as well as the M54 trucks, have fair mobility over the assumed mission environment, with engineer support needed in segments 3 and 5 and to a lesser extent in segments 8 and 9. The average speed throughout the environment for all these trucks is 7.4 miles per hour, including the advantage taken of engineering support. Fuel consumptions given in Tables 31 and 33 are for presently used gasoline engines. Future incorporation of multifuel engines, now under development, would reduce fuel consumption about 25 per cent on the average, if diesel fuel is used (fuel consumption in pounds per mile). See References 51, 54, and 57. Fuel consumptions given in Tables 31 and 33 will be used in the cost/effectiveness comparison in the next section. Operations in environmental segment 7 assume the use of desert tires for increased traction.

The performance of the 5-ton GOER XM520 is given in Tables 34 and 35. Tests by the Armor Board, reported in Reference 56, show that this vehicle is space-limited to about 4 tons payload for Class I and Class III cargoes. Accordingly, an average payload of 4.5 tons has been used in the cost/effectiveness comparison. The XM520 GOER is somewhat more mobile than the 6 by 6 trucks, but still requires engineering support in segments 3 and 5. The average speed throughout the environment is 7.7 miles per hour. Due to lack of data, fuel consumption is, for the most part, estimated, based on power and performance comparison with the XM437 GOER. Therefore, an additional 10 per cent has been added in Table 35 to cover errors in this method.

Performance of the 15-ton GOER XM437 is given in Tables 36 and 37. This vehicle is also space-limited for all cargoes except Class V. An

average payload of 12.5 tons has been used in the cost/effectiveness comparison. The XM437 is the most mobile of the wheeled vehicles in the analysis, requiring engineer support only in route segment 5. The average speed over the entire route is 7.5 miles per hour.

The M52/M127 truck tractor-semitrailer combination is the least mobile of all the vehicles in the analysis. Engineering support is required in segments 3, 4, 5, 8, and 9; and segment 7 is extended by 25 per cent to avoid the higher dunes. Desert tires and "all-terrain" type tires are assumed to be used in appropriate segments. After provision of considerable engineer support, an average of 7.1 miles per hour can be achieved, as shown in Table 39.

The CH-47A helicopter can operate independently of the land terrain. Because it can fly straight-line route segments, a 70-mile air range is equivalent to 100 miles land range. The nominal internal payload of the Chinook with Lycoming T55-L5 engines is 3 tons; but at ranges less than 100 miles, this can be increased to 4 tons. Fuel consumption in cruise averages 13.5 pounds per miles, and the block speed over the two 35-mile legs is 110 miles per hour (all helicopter performance figures converted to statute miles and statute miles per hour).

Costs associated with the performance data summarized in Tables 29 through 41, and the comparison of relative effectiveness and costs, are given in the next section.

4.4 COST/EFFECTIVENESS COMPARISON

The vehicle mobility and performance data summarized in Tables 29 to 41, may be combined with similar data developed for the optimized off-road ACV's in Chapter II. Costing data from Chapter III and Section 4.2 are then incorporated. Additional costs which may be distinguished on the basis of the type vehicle used must be added. Finally, the relative cost/effectiveness of each mobility system can be determined.

Combination of the inputs listed above can best be done in the following manner:

1. Select the assumed mission parameters - Sections 4.1 and 4.3.

2. Within these assumed mission parameters (environment payload range), determine the mobility and performance of each vehicle type:

- (a) Average speed
 - (b) Fuel consumed
- See Tables 29 through 41, and Table 10 in Chapter II.

3. For each vehicle type, determine the over-all trip time and payload per trip.

- (a) Route time, from Tables 29 through 41 and Table 10.
- (b) Load-unload and terminal times, from References 3, 56, and 62, and Table 44.
- (c) Payload, from Tables 19 through 25.

For each vehicle type, determine number of trips per day.

- (a) Operating time per day from References 2, 3, and 62, and Table 44.

5. For required tonnage, determine number of operating vehicles required.

6. From availability rates, determine total number of vehicles to be assigned, based on References 2 and 62 and Table 44.

7. For each vehicle type, determine operating costs:

- (a) First cost from Tables 18 and 25.
- (b) Maintenance cost from Tables 18 and 25.
- (c) Crew cost from Tables 18 and 45.
- (d) Fuel costs from Tables 18 and 45.

8. For each vehicle type, determine engineer support costs:

- (a) Engineer support requirements from Tables 29 to 41.
- (b) Engineer support assumptions and costs from References 30 and 35.

TABLE 44
TIME ELEMENTS IN LOGISTICS MISSION

The following time elements for logistic missions were taken from References 2 and 3, with other references listed below.

Motor transport planning factors, Ref. FM 101-10

1. Load and unload trucks, logistic cargoes, 2-1/2 hours per round trip.
2. ~~Tractor-semitrailer relay~~ time (2 trailers for each tractor) 1 hour per relay, 2 hours per round trip.
3. Load and unload 12-ton semitrailer, 4 hours per round trip.
4. Load and unload 15-ton GOER, 4 hours per round trip.
Ref. Report of Armor Board Evaluation,
Proj. No. 2038, Ref. 56.
5. Operating day - 1 shift 10 hours
 - 2 shifts 20 hours
6. Availability - 75 per cent

Use above truck parameters 1. 5. 6 for off-road GEM

Table 44 (continued)

Helicopter planning factors, Ref. FM 101-10 & TCCG 61-83(sp)

7. Load and unload interior cargo - 20 minutes
(5 min. each in 101-10, but larger payload in Chinook)

In view of the types of logistical cargo being considered in this study, this value is unrealistically short. After discussing with TRECOM, it was agreed that a value consistent with that used for the surface vehicles of similar payload would be more appropriate. Accordingly, a load-unload time of 2.5 hours per round trip has been used in the analysis.
8. Operating day, 12 hours, but each helicopter limited to 4-5 flight hours.
9. Availability - 67 per cent

Use operating time of 4 flying hours daily, not including load-unload time (assign one flight crew to each operating helicopter for full shift)
10. Maneuver time for helicopter

Assume 5 minutes per leg, 10 minutes per round trip
11. Net block speed as function of air range. From Ref.

Air Range (s. mi.)	Air Time (min.)	Block Speed (mph)	Corresponding Ground Range (s. mi.)
175	80	130	(250)
70	38	110	(100)
35	24	85	(50)
17.5	17	60	(25)

9. For each vehicle type, determine total system costs from (7) and (8) above.
10. Tabulate system costs and compare.

Note that each system is made to do the job, and that costs are only an index of the materiel and personnel required to carry out the operation.

After completion of this cost/effectiveness comparison, the mission range and/or environment may be varied to determine changes in cost/effectiveness.

Note: The foregoing procedure, while derived entirely independently, is analogous to the method outlined in the Ordnance Corps Land Locomotion Research Branch Report 40, "Operational Definition of Mechanical Mobility of Motor Vehicles", by M. G. Bekker, Reference 63. Reference 63 treats the same elements of effectiveness and costs, but within a more codified framework of analysis.

Items 1 through 6 of the cost/effectiveness comparison can be conveniently carried out in tabular form. The application of this method to the 100-mile range mission is given in Table 46. The input data for this table are from the sources given above, with ACV data from Chapters II and III, and comparative vehicle data from Section 4.3. Time elements in logistic missions are listed in Table 44, including load-unload times, operating day, and availability rate.

Because the selection of range and mission environment has been arbitrary, it has been assumed that fractional numbers of trips can be made. This provides a better basis for comparison of vehicles than use of integral trips only, since (with the latter method) small changes in range may have an unrealistic effect on the relative numbers of vehicles required.

Item 7 can be determined as follows: first costs, amortization times, and maintenance costs are from Table 26 in Section 4.2 (except for the ACV's, which are in Section 3.2 and 3.3). Crew costs and fuel costs are given in Table 45. All surface vehicles are assumed to carry two crew members throughout the operation (this would require reinforcing the truck companies, TOE 55-17 and TOE 55-18, where two-shift (20-hour) operations leave only one crew member per vehicle). Numbers of vehicles required and assigned, and total amount of fuel used, are given in Table 46.

TABLE 45
MANPOWER AND FUEL COSTS

The following cost bases were derived or given in Ref.
from data in Ref.

Fuel costs:

gasoline (motor fuel)	\$.025 per pound
diesel fuel	.013 per pound
JP-4	.015 per pound

Manpower costs:

vehicle operators and maintenance (per man-hour)
\$1.43 per man-hour
(assumed applicable to ACV)

Engineer support personnel (per effective man-hour construction
effort)

\$2.60 per effective man-hour construction effort

Helicopter flight crew personnel (Chinook)

(captain, warrant officer, corporal)

\$15.00 per flight hour

TABLE 46 COST/EFFECTIVENESS COMPARISON - OPERATIONAL PARAMETERS													
Mission: deliver 369 tons/day, 40 miles forward (100 miles range), 28 air miles forward (70 miles air range)													
Vehicle	Turbine												
	M35/M135	M54	XM520	XM437	RN110	M52/M127	CH47A (HC-1B)	Pure ACV	Wheeled ACV	Pure ACV	Wheeled ACV	Pure ACV	Wheeled ACV
Payload (tons)	2.5	5	4.5 average	12.5 average	5.5	12	4	2.2 4404 lb.	3.6 7109 lb.	2.6 5248 lb.	3.7 7368 lb.		
Average speed (mph)	7.4	7.4	7.7	7.5	7.5	7.1	110	9.1	11.5	9.1	11.5		
Load/unload time (hr)	2.5	2.5	2.5	4	2.5	2.0 shuttle	2.5	2.5	2.5	2.5	2.5		
1-Trip time (hr)	16.0	16.0	15.5	17.4	15.8	16.0	3.1 63 flying hrs	13.5	11.2	13.5	11.2		
Operational day (hr)	20	20	20	20	20	20	12 4 flying hrs.	20	20	20	20		
Trips per day	1.25	1.25	1.29	1.15	1.27	1.25	4	1.48	1.78	1.48	1.78		
Tons per day	3.12	6.25	5.80	14.4	7.0	15	16	3.26	6.40	3.88	6.55		
Number of vehicles req'd.	119	60	64	26	53	25	24	113	59	95	57		
Availability rate (%)	75	75	75	75	75	75	67	75	75	75	75		
Number of vehicles assigned	160	80	85	35	71	34 + 34x2 trailers	36	151	78	127	76		
Fuel per trip (lb.)	252 gas.	396 gas.	260 diesel	428 diesel	460 gas.	471 gas.	950 JP-4	5380 JP-4	2090 JP-4	3330 gas.	1240 gas.		
Total fuel per day (lb.)	~38,000	~30,000	~21,000	~13,000	~31,000	~15,000	~90,000	~900,000	~216,000	~467,000	~126,000		

Item 8, engineer support costs, requires a separate determination, which is given below:

In Tables 29 to 41, the requirements for direct engineer support were outlined for each vehicle. Inclusion of engineer support direct costs in the cost/effectiveness comparison is a means of balancing the varying mobility performance of the vehicles over the assumed mission environment. By determining the direct cost of the support required to permit operation throughout the entire route, and amortizing this cost over selected operational periods, the total costs of the use of each vehicle type can be determined.

From Tables 29 to 41, the following vehicle/route segment combinations require engineering support:

- M35, M135, and M54, segments 3, 5, 8, and 9
- XM520, segments 3 and 5
- XM437, segment 5
- RN-110, segment 3
- M52/M127, segments 3, 4, 5, 8, and 9
- Skirted "free" ACV, segment 4
- Skirted ACV, with wheels - none
- CH-47A helicopter - none

Review of Tables 29 to 41 shows that the engineer support for each segment is almost the same for all vehicles requiring support in that segment. Table 47 summarized the engineer support required, by segments of the assumed mission environment. (Route mileage one way is assumed to be 40 per cent of the total operating range.) From Table 47, it can be seen that engineer support types consist of bridging or ferrying in segment 3 and pioneer road building and similar construction in segments 4, 5, and 8, with some sort of vehicle assistance required in segment 9. The last item is assumed to be available for the 2-1/2- and 5-ton trucks from other vehicles in their organization; while some sort of towing vehicle might be assigned full time to enable the M52/M127 combination to navigate the rain-soaked, rutted road. Representation of engineer support for all vehicles is given in Figure 33.

Pioneer road building would be accomplished by units of an Engineer Combat Company, while bridge or raft emplacement would be accomplished by an Engineer Float Bridge Company. In both cases, the direct cost, in man-hours, would be amortized over an arbitrary

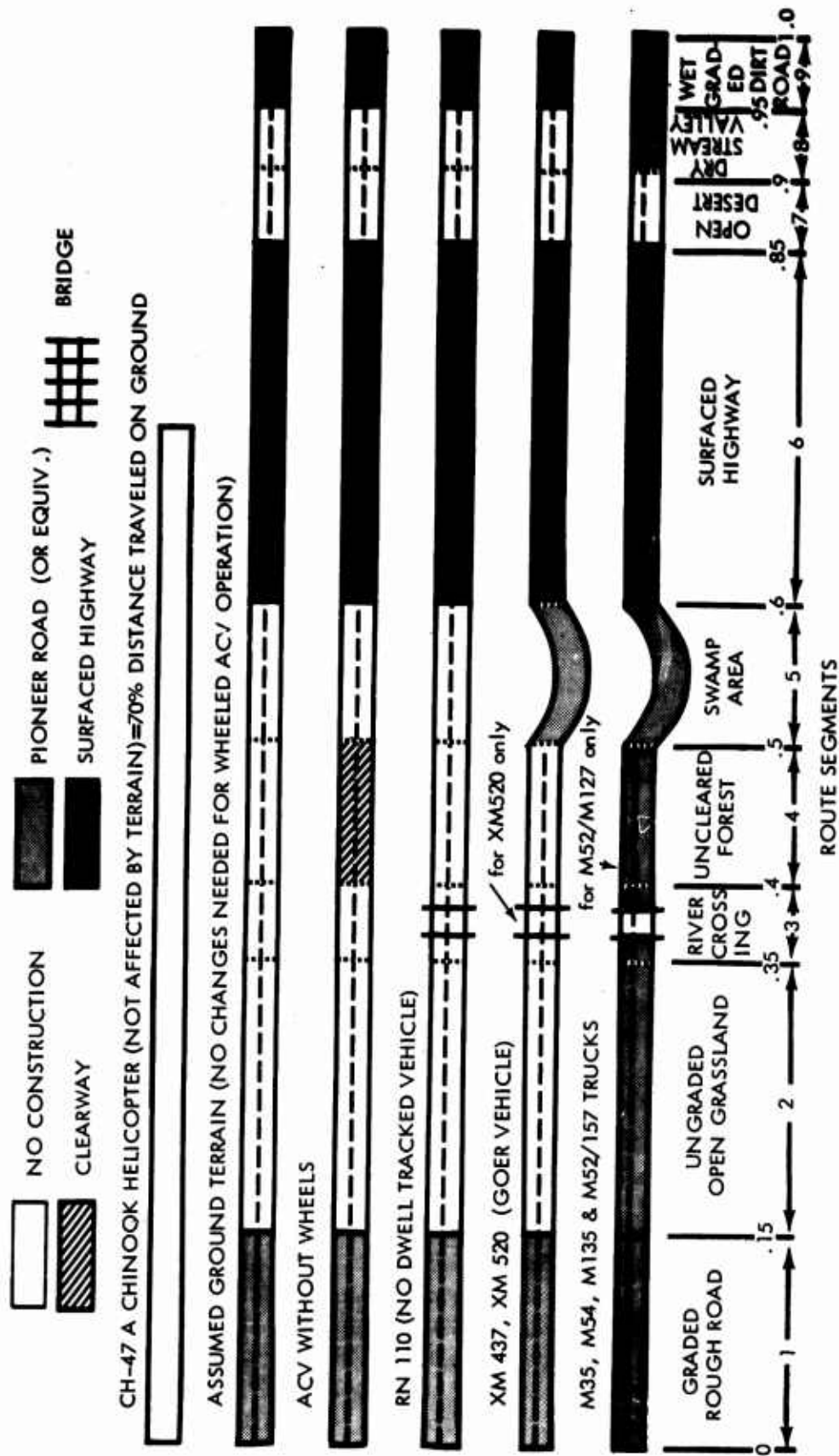


Figure 33 Terrain Characteristics and Route Structure

period of operation. The selected periods of operation assumed for this study are 30 days and 90 days. With reuseable bridging components, only manpower is considered to be chargeable during construction. Delay times are also considered. The basis of computation is 40 route miles (100 miles range).

Provision for the nonfloating vehicles to operate in route segment 3 is assumed to be provided through a floating bridge or rafts. Either of these modes can be furnished by an Engineer Float Bridge Company, TOE 5-78E. Data in FM 101-10 show that the normal bridging requirement per road mile is approximately 40 feet. This was confirmed by review of the report of an environmental operation in a tropical area, Reference 44. For purposes of this study, all waterways requiring bridging are assumed to be within segment 3, with the referenced length of 40 feet per route mile. Since segment 3 covers 5 per cent of the assumed mission environment, or 260 feet per route mile, the remainder of the segment is assumed to consist of fordable waterways (less than 3-foot depth) and access routes, which must be constructed.

For the 100-mile mission (route distance, 40 miles), the water gap to be bridged or ferried is 1,600 feet; and the requirement for a two-lane pioneer-type access road is assumed throughout the rest of the segment, or 1.7 miles. (No access road is required for GOER vehicles or the Nodwell RN-110.) For the M52/M127 combination, a bridge or raft of Class 24 is required (Table 47); for the other vehicles, the highest bridge class is Class 15. A current of 5 knots is assumed.

Bridging times are given in FM 101-10, paragraph 4.30 d, and in FM 5-34, paragraphs 52, References 3 and 35.

Bridge Type	Normal Crossing Class	Construction Working Party	Construction Time (daylight only)	Construction Man-Hours per 100 ft.
M4T6	45 wheeled 55 tracked	120	100 ft/hour	120
Light tactical	16	60	200 ft/hour	30

TABLE 47
ENGINEER SUPPORT REQUIREMENTS

Segment	Per Cent of Route	Vehicle(s)	Engineer Support
3. River crossing	5% bridging only, no access road	M35, M135 (9)* M54 (15) RN-110 (11) XM520 (13) M52/M127	Bridging (one-way) or ferry required, with access road, pioneer type, two- way
4. Uncleared forest	10%	M52/M137	Pioneer road, two-way clearing and grading
5. Swamp	10%	Skirted "free" GEM M35, M135, M54 XM520, XM437 M52/M127	Clearway, 30 feet wide, clearing only
8. Dry-stream valley	5%	M52/M127	Pioneer road two-way, around swamp area, at 1.5 x route distance. Compute time and fuel over longer route.
9. Rutted, muddy road with obstacles	5%	M35, M135, M54 M35, M135, M54 M52/M127	Clear and/or fill rocky area as for pioneer road, one-lane, equivalent to full distance Same as for M52/M127, but only 1/4 distance equivalent Winching or tow required in spots, assumed available Towing required, add fuel and manpower for 1 tractor (full tracked) full time

* Numbers in parentheses denote bridge classes.

For short spans (less than 500 feet), a somewhat greater proportional number of man-hours are required, to prepare abutments. For the assumed mission distanced in this study, 100 miles, the corresponding bridging requirement is 1,600 feet.

Length of spans (assumed)	1,000 and 600 feet
Total	1,600
M4T6 bridge (man-hours)	1,920
Light tactical bridge (man-hours)	480

The M4T6 bridge, which is required for the M52/M127, could be replaced by M4T6 rafts, which can be erected with 60 man-hours each. However, over a period of time as long as 30 days, the operating manpower required would be much more expensive than by use of bridging.

Combat Engineer man-hour costs are derived in Reference 16, equivalent to \$2.60 per working man-hour. Applying this factor, the cost of erecting floating bridging in route segment 3 is given below:

Vehicle	Range	Bridging distance	Bridge type	Erection cost
M52/M127	100 mi.	1,600 ft.	M4T6	\$5,000
M35, M135 M54, XM520 RN-110	100 mi.	1,600 ft.	light tactical	1,250

Note that erection of 1,600 feet of bridging ties up the normal full stock of two floating bridge companies. However, erection of fixed bridges is more costly in terms of manpower required.

In addition to the bridge erection costs calculated above, engineering support in route segment 3 also includes construction of access roads (pioneer type, two-way). Cost of this is computed below.

Engineer support in segments 4, 5, and 8, where needed, consists of pioneer road construction. This would be accomplished by an Engineer Combat Company, TOE 5-37D. The construction effort required for typical pioneer road construction is given in FM 101-10, Reference 3. These figures include clearing, grubbing, stripping, and rough grading 1 mile of two-way combat road 24 feet wide (no culverts, bridging, or surfacing):

<u>Terrain</u>	<u>Two-way pioneer road, man-hours per mile</u>
Flat - prairie	2, 200
Rolling	2, 800
Hilly, forested	3, 300

For route segment 4, construction of a road for the M52/M127 would correspond to "hilly, forested", or 3,300 man-hours per mile. For route segment 5, construction of a road around the swamp area would correspond to "flat - prairie", at 2,200 man-hours per mile. In this case, the road construction required is assumed to be 1.5 times the route distance (across the swamp). This construction cost would be applied to the M35, M135, M54, XM520, XM437, and M52/M127.

In route segment 8, clearing of larger rocks (or filling) is required for the M52/M127, and over part of the distance for the M35, M135, and M54 trucks. This is assumed to be provided by a bulldozer at the rate of 110 yards per hour, based on data in Table 76 of FM 5-34 (12 feet wide only). This corresponds to 16 hours per mile for one man and bulldozer (count 2 men + fuel at 65 lb. per hour).

In route segment 4, the clearway required for the skirted "free" ACV would be less costly than a pioneer road over the same route, since only clearing would be required. From FM 5-34, the manpower requirements for light clearing of a 30-foot-wide strip plus small trees (separation 20-30 feet) is 25 man-hours per 100 yards plus 1.5 man-hours per tree. At a calculated average of 18 trees per 100 route yards, the total construction effort required is 52 man-hours per 100 yards, or 920 man-hours per mile. An engineer tractor with dozer blade could accomplish the same result at a rate of one acre per hour or 20 trees per hour, altogether about 25 hours per mile.

The construction effort for access roads to bridging in route segment 3 corresponds to "rolling", at 2,800 man-hours per mile.

Road maintenance requirements are estimated in FM 101-10 to be 15 man-hours per mile per day. These figures, and all the above, are based on statute-mile distances.

All the above engineer direct support requirements are costed at the rate of \$2.60 per man-hour, as derived in Reference 3. The engineer direct support costs for each segment are given in Table 48, based on

Segment	Percent	Vehicle	Support	Man-hours	Dollars
3	5%	M35, M135, M54, XM520 RN110	light tactical bridging 1,600	480	\$1,250
		M52/M127	M4T6 bridging	1,920	\$5,000
		M35, M135 M54, M52/M127	1,600 feet access road, 2-lane pioneer, 1.7 miles	4,750	\$12,360
4	10%	M52/M127	2-lane road - 4 mi.	13,200	\$34,300
		Skirted "free" ACV	30 ft. clearway 4 miles	3,680	\$9,550
5	10%	M35, M135 M54, XM520 XM437, M52/M127	2-lane pioneer road 1.5 x 4 miles	13,200	\$34,300
8	5%	M52/M127	one lane clear rocks & fill 2 miles		\$200.00 50.00
		M35, M135 M54	same 1/2 mile		
9	5%	M52/M127	towing tractor, 3 men at 10 hrs. 20 hrs/ day during operation daily fuel at 65 lb/hr		\$104 per operating day
1, 3, 4, 5, 6	70%	M52/M127	maintenance 28 miles		\$1,080 per operating day
1, 3, 5 6	60%	M35, M135 M54	maintenance 24 miles		\$940 per operating day
1, 6	35%	XM520, XM437 RN110	maintenance 14 miles (preventive)		\$545 per operating day

TABLE 49
ENGINEER SUPPORT COSTS (VEHICLE)

Vehicle	Daily maint. & operation	Construction & bridging		Total Cost	Construction & bridging ÷ 30 ÷ 90		Total support cost daily	
		Segments	days		days	days	30 days	90 days
M35, M135 M54	\$940 maint.	3, 5, 8		\$47,960	\$1,600	\$535	\$2540	\$1475
XM520	\$545 maint. preventive	3, 5		35,550	1,185	395	1730	940
XM437	\$545 maint. preventive	5		34,300	1,145	380	1690	925
RN 110	\$545 maint. preventive	3		1,250	42	14	590	560
M52/M127	\$1180 maint. and operation	3, 4, 5, 8		86,160	2,875	960	4055	2140
Skirted "free" ACV	none	4		9,550	320	105	320	105
ACV with wheels	\$545 maint. preventive	none					545	545
CH-47A helicopter	none	none						

100 miles operating range (40 route miles). These same costs are summed for each vehicle type in Table 49. To the daily maintenance and operating support costs are added construction costs amortized over 30 or 90 days of operation. The skirted "free" ACV is assumed to have no associated road maintenance cost, since there is no ground contact. The ACV with wheels is assumed to have associated preventive maintenance on route segments 1 and 6, where it operates on its wheels over present road systems. Total support costs are given in the last two columns of Table 49.

Operational delay due to requirements for engineer support should also be considered. As a first approximation, it is assumed that one Engineer Float Bridge Company and two Engineer Combat Companies are assigned to do the work. With an effective construction rate of 1,400 man-hours per combat company per day (derived from Reference 3), the time required to complete all construction and bridging needed by each vehicle type would be approximately as follows: (40 route miles)

M35, M135, M54 truck	6.5 days
XM520, XM437 GOER	5 days
RN110 Nodwell Transporter	1 day (bridging only)
M52/M127 truck tractor-semitrailer	11 days
Skirted ACV	1-1/2 days (clearway)
ACV with wheels	none
CH-47A Helicopter (Chinook)	none

Total system costs, can be determined by summing the operating costs and engineer support costs derived above. This can also be conveniently done in tabular form. Table 50 gives the direct costs associated with the 100-mile range mission. The inputs to Table 50 are from the previous Tables 26, 45, 46, 49, as explained in the notes. For this first comparison of costs, engineer support will be assumed to be amortized over a 30-day operation. The effect of amortizing engineer support over a 90-day operation is shown below:

TABLE 50 COST/EFFECTIVENESS COMPARISON - TOTAL COSTS PER DAY											
Mission: deliver 369 tons/day, 40 miles forward (100 miles range), 70 miles air range											
Costing Parameter	M35/M135	M54	XM320	NM437	RN110	M52/M127	CH47A (HC-1B)	Turbine		Reciprocating	
								Pure ACV	Wheeled ACV	Pure ACV	Wheeled ACV
											100 miles GEMINI
Number required	11 ^a	10	64	26	53	25	24	113	59	75	57
Number assigned	16.0	80	85	35	71	34 ^a 34 trailers	36	151	78	95	76
Total fuel used per day (lb)	38,000 gas	30,000 gas	21,000 diesel	13,000 diesel	31,000 gas	15,000 gas	90,000 JP-4	900,000 JP-4	216,000 JP-4	467,000 gas	126,000 gas
Costs of fuel per day	\$ 950	\$ 750	\$ 270	\$ 170	\$ 775	\$ 375	\$ 1,350	\$ 13,500	\$ 3,240	\$ 11,700	\$ 3,150
Costs of crew	6,800	3,430	3,660	1,490	3,030	1,430	2,880	6,460	3,380	4,290	3,260
Engineer support (30 day operation)	2,540	2,540	1,730	1,690	580	4,055	--	320	545	320	545
Vehicle amortization	3,600	3,600	1,450	1,920	2,060	2,300	20,180	74,500	23,400	23,800	13,600
Maintenance	3,600	3,600	1,450	1,920	2,560	2,300	28,800	36,000	11,200	11,200	6,260
Total direct costs	\$17,490	\$13,920	\$8,560	\$7,210	\$9,015	\$10,460	\$53,210	\$130,780	\$41,765	\$51,310	\$26,815
Cost/ton mile forward	1.19	.95	.58	.49	.61	.71	3.61 (5.15)	8.86	2.83	3.48	1.82
Notes:	lines 1, 2, 3, from Table 46.										
	lines 4, 5 from Table 45, based on number of vehicles required (line 1) and 2-10 hr shifts with 2 crew for surface vehicles, 1-12 hr shift for helicopter										
	line 6 from Table 49, based on 30 day operation										
	lines 7, 8 from Table 20, based on number of vehicles assigned (line 2).										

<u>100-mile mission total costs per day</u>	<u>30 day operation (Table 50)</u>	<u>90 day operation (use cost differential in Table 49)</u>
M35, M135	17,490	16,425
M54	13,920	12,855
XM520	8,560	7,770
XM437	7,210	6,455
RN110	9,015	8,985
M52/M127	10,460	8,545
CH-47A	53,210	53,210
Pure ACV*	51,310	51,095
ACV with wheels*	26,815	26,815
GEMINI	39,710	39,710

* Reciprocating engines.

Variation of Range

The significant effects of mission operating range on the cost/effectiveness comparison can be determined by repeating the above analysis for ranges of 50 miles, 25 miles, and 250 miles (corresponding air ranges of 35 miles, 17.5 miles, and 175 miles). The procedure is the same as that described above; but payloads (for the helicopter and the ACV's), trip times, fuel consumed, and numbers of vehicles required and assigned are modified to reflect the variations in range. Costs are then determined for these new parameters, including the variation in engineer support costs.

Table 51 gives operational parameters associated with the 50-mile mission, and Table 52 gives corresponding daily costs. Thus, Tables 51 and 52 may be directly compared with Tables 46 and 50. Tables 53 and 54 give the similar cost/effectiveness comparison for the 25-mile mission, all with the same tonnage required (369 tons per day) and the same assumed mission environment.

Figure 44 shows the cost comparison for the 25-, 50-, and 100-mile missions. Costs are total direct costs divided by the daily tonnage times the number of miles forward. All these costs are based on a 30-day operation. Change of operating period would affect engineer support cost only. It must be kept in mind that response time in any operation would be dependent on the construction delays associated with engineer support, as given on page 169.

TABLE 51 COST/EFFECTIVENESS COMPARISON - OPERATIONAL PARAMETERS													
Mission: deliver 369 tons/day, 20 miles forward (50 miles range), 14 air miles forward (35 miles air range)													
Vehicle	M35/M135	M54	XM520	XM437	RN110	M52	M127	CH-47A (HC-1B)	Turbine		Reciprocating		50 miles GEMINI
									Pure ACV	Wheeled ACV	Pure ACV	Wheeled ACV	
Payload (tons)	2.5	5	avg. 4.5	avg. 12.5	5.5	12	4	4	3.5	4.1	3.5	4.0	1.25 tons
Average speed (mph)	7.4	7.4	7.7	7.5	7.5	7.1	85	85	9.1	11.5	9.1	11.5	9.7
Load/unload time (hrs)	2.5	2.5	2.5	4.0	2.5	shuttle 2.0	2.5	2.5	2.5	2.5	2.5	2.5	1.0
1-trip time (hrs)	9.25	9.25	9.0	10.7	9.2	9.0	2.9	2.9	8.0	67	8.0	6.7	6.2
Operational day (hrs)	20	20	20	20	20	20	12 hrs 4 flying hrs	20	20	20	20	20	20
Trips/day	2.16	2.16	2.22	1.87	2.18	2.22	5	5	2.5	3.0	2.5	3.0	3.23
Tons/day	5.4	10.8	10.0	23.4	12.0	26.6	20	20	8.9	12.3	8.7	12.0	4.04
Number vehicles required	68	34	37	16	31	14	18	18	41	30	42	31	92
Availability rate - %	75	75	75	75	75	75	67	67	75	75	75	75	75
Number vehicles assigned	91	46	50	22	41	19	27	27	55	40	56	41	122
Fuel per trip (lb)	126	198	130	214	230	236	500	500	2690	1050	1670	620	316
Total fuel per day (lb)	18,500	14,500	10,700	6,400	15,500	7,000	48,000	48,000	275,000	95,000	175,000	58,000	93,000

TABLE 52 COST/EFFECTIVENESS COMPARISON - TOTAL COSTS PER DAY												
Mission: deliver 369 tons/day, 20 miles forward (50 miles range), 35 miles air range												
Costing Parameters	M35/M135	M54	XM520	XM437	RN110	M52/M127	CH-47A (HC-1B)	Turbine		Reciprocating		50 miles GEMINI
								Pure ACV	Wheeled ACV	Pure ACV	Wheeled ACV	
Number required	68	34	37	16	31	14	18	41	30	42	31	92
Number assigned	91	46	50	22	41	19	27	55	40	56	41	122
Fuel per day (total lb)	18,500 gas	14,500 gas	10,700 diesel	6400 diesel	15,500 gas	7000 gas	48,000 JP-4	275,000 JP-4	95,000 JP-4	175,000 gas	58,000 gas	93,000
Costs of fuel/day	\$ 465	\$ 365	\$ 140	\$ 85	\$ 390	175	720	\$ 4,130	\$ 1,425	\$ 4,380	\$ 1,450	2,330
Costs of crew	3,890	1,950	2,115	915	1,770	800	2,160	2,340	1,715	2,400	1,770	2,630
Engineer support (30 days)	1,270	1,270	865	845	295	2,030	--	160	275	160	275	--
Vehicle amortization	2,050	2,070	850	1,210	1,190	1,280	15,150	27,100	12,000	14,000	7,350	6,100
Maintenance	2,050	2,070	850	1,210	1,475	1,280	21,600	13,200	5,720	6,600	3,375	6,100
Total direct costs	\$9,725	\$7,725	\$4,820	\$4,265	\$5,120	\$5,565	\$39,630	\$46,930	\$21,135	\$27,540	\$14,220	17,160
Cost/ton mile forward	1.32	1.05	.65	.58	.69	.75	5.35 (7.65)	6.35	2.86	3.73	1.93	2.32
Notes: See Table 50.												

TABLE 53 COST/EFFECTIVENESS COMPARISON - OPERATIONAL PARAMETERS												
Mission: deliver 369 tons/day, 10 miles forward (25 miles range), 7 air miles forward (17.5 miles air range)												
Vehicle	M35/M135	M54	XM520	XM437	RN110	M52/M127	CH-47A (HC-1B)	Turbine		Reciprocating		25 miles GEMINI
								Pure ACV	Wheeled ACV	Pure ACV	Wheeled ACV	
Payload (tons)	2.5	5	avg. 4.5	avg. 12.5	5.5	12	4.5	4.2	4.3	3.9	4.1	1.3 tons
Average speed (mph)	7.4	7.4	7.7	7.5	7.5	7.1	60	9.1	11.5	9.1	11.5	9.7
Load/unload time (hrs)	2.5	2.5	2.5	4.0	2.5	2.0 shuttle	2.5	2.5	2.5	2.5	2.5	1.0
1-trip time (hrs)	5.9	5.9	5.75	7.4	5.8	5.5	2.8	5.25	4.7	5.25	4.7	3.6
Operational day (hrs)	20	20	20	20	20	20	12 hrs 4 flying hrs	20	20	20	20	20
Trips/day	3.4	3.4	3.5	2.7	3.45	3.65	5	3.8	4.25	3.8	4.25	5.56
Tons/day	8.5	17.0	15.7	33.8	19.0	43.8	22	16.0	18.4	14.7	17.6	7.25
Number vehicles required	44	22	24	11	20	9	17	23	20	25	21	51
Availability rate - %	75	75	75	75	75	75	67	75	75	75	75	75%
Number vehicles assigned	58	29	32	15	27	12+ 12 trailers	25	31	27	34	28	68
Fuel per trip (lb)	63	99	65	107	115	118	300	1345	525	835	335	160
Total fuel per day (lb)	9400	7400	5500	3200	8000	3900	25,500	117,000	44,500	79,000	30,000	45,500

TABLE 54 COST/EFFECTIVENESS COMPARISON - TOTAL COSTS PER DAY													
Mission: deliver 369 tons/day, 10 miles forward (25 miles range) (17.5 miles air range)													
Costing Parameters	M35/M135	M54	XM520	XM437	RN110	M52/M127	CH-47A (HC-1B)	Turbine		Reciprocating		25 miles GEMINI	
								Pure ACV	Wheeled ACV	Pure ACV	Wheeled ACV		
Number required	44	22	24	11	20	9	17	23	20	25	21	51	
Number assigned	58	29	32	15	27	12+ 12 trailers	25	31	27	34	28	68	
Fuel per day (total lb)	9400 gas	7400 gas	5500 diesel	3200 diesel	8000 gas	3900 gas	27,000 JP-4	117,000 JP-4	44,500 JP-4	79,000 gas	30,000 gas	45,500	
Cost of fuel per day	\$ 235	\$ 185	\$ 75	\$ 45	\$ 200	\$ 100	\$ 385	\$ 1,760	\$ 670	\$ 1,975	\$ 750	1,140	
Cost of crew per day	2,510	1,255	1,370	630	1,145	515	2,040	1,315	1,145	1,430	1,200	1,460	
Engineer support (30 days)	640	640	435	425	150	1,020	--	80	140	80	140	--	
Vehicle authorization	1,310	1,310	545	825	785	810	14,000	13,300	8,100	8,500	5,000	3,400	
Maintenance	J, 310	1,310	545	825	970	810	20,000	7,400	3,860	4,000	2,300	3,400	
Total direct costs	6,005	4,700	2,970	2,750	3,250	3,255	36,425	23,855	13,915	15,985	9,390	9,400	
Cost/ton mile forward	1.63	1.27	.80	.74	.88	.88	9.87 (14.10)	6.46	3.78	4.33	2.54	2.55	
Notes: See Table 50.													

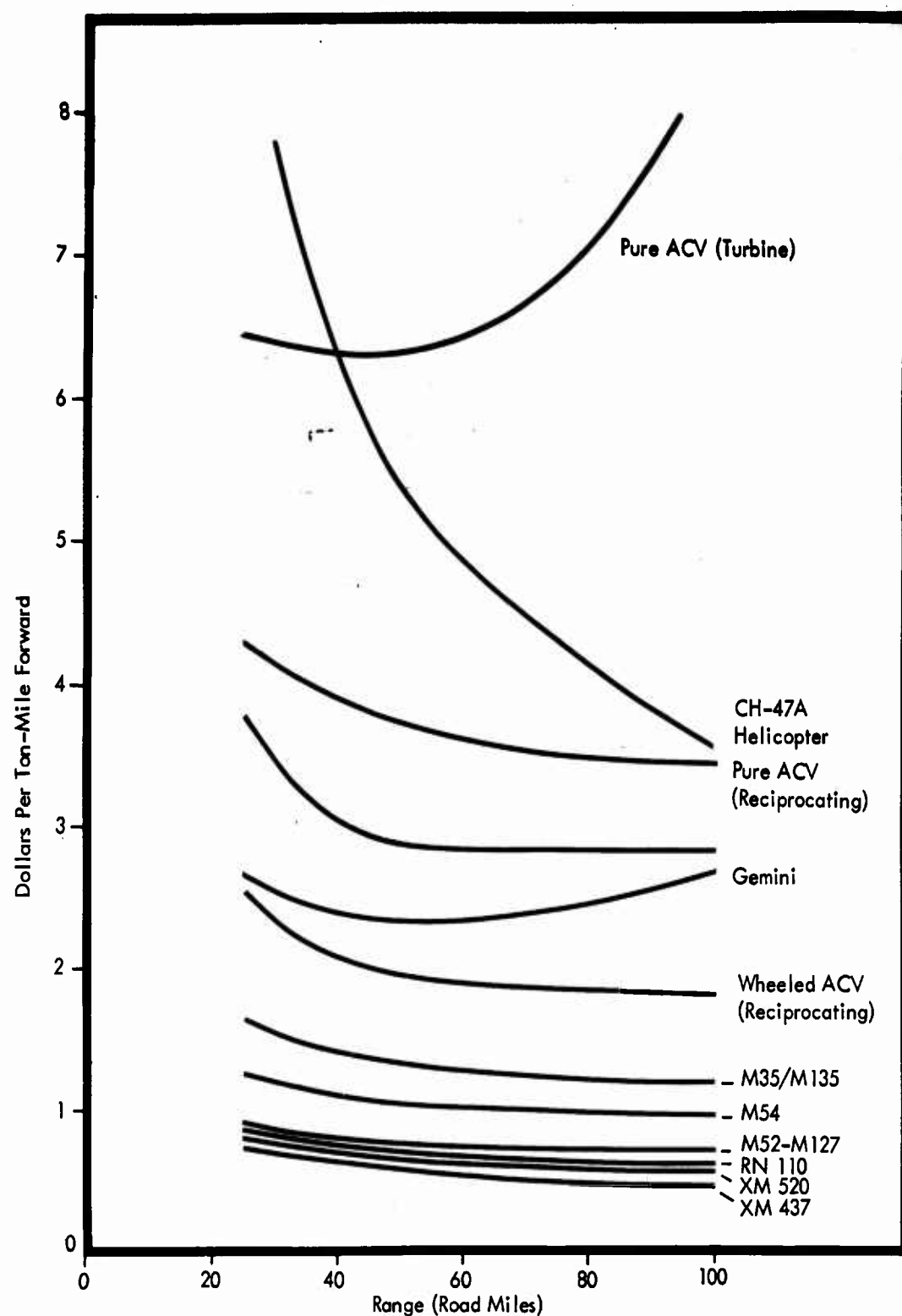


Figure 34. Ton-Mile Cost Comparison of Off-Road Vehicle And The Chinook Helicopter Against Range

CHAPTER V

IMPACT OF AIR CUSHION VEHICLES ON OFF-ROAD LOGISTICS OPERATIONS

5.1 MOBILITY ASPECTS OF THE OFF-ROAD ACV

The analysis of the preceding chapters has highlighted the favorable and unfavorable aspects of the use of air cushion vehicles in support of the off-road logistic mission. Some of the results could have been intuitively predicted, such as, that ACV's have much higher initial costs than trucks of equal payload. In other areas, the analysis has provided new insight into such significant parameters as the critical nature of the gradability requirement.

Mobility aspects of overland ACV's have been emphasized in this study, an emphasis entirely justified by the importance of improving mobility in off-road logistic operations. Both the pure ACV and the ACV with wheels can be considered as "more mobile" (than other surface vehicles) in the assumed mission environment, if average speed of moving cargoes is a fair criterion of mobility.

Mobility advantages of ACV's over other surface vehicles are maximum in areas of soft, sticky and wet surfaces (including water). The ability to maintain headway over these terrains without construction delays or laborious assistance is probably the most significant advantage of the ACV in off-road operations.

Configuration was found to be important to mobility, inasmuch as the ACV with wheels was found to be superior to the pure ACV with regard to propulsion power required to hold a grade, and ease of traversing "congested" routes such as wooded areas. In general, the requirement that an air cushion vehicle be used in primarily overland operations appears synonymous with the requirement that the vehicle have some sort of ground contact.

One interesting aspect of mobility is the effect on response times. While a "nonmobile" vehicle such as the M52/M127 combination can be operated through the assumed off-road environment by application of sufficient engineer support, the time factors involved may

preclude such activity. While the amortized cost of engineer support was not found to be excessive if operations could be maintained for 30 days or more, the construction time for access and bypass roads could be very critical to success of a rapid supply build-up in a forward area. Here, again, the wheeled ACV showed superiority in the assumed environment over the pure ACV.

The performance of the GEMINI-type vehicle is in good agreement with the optimum wheeled ACV, particularly when the lower payload capability of the GEMINI is taken into account. As expected, the size investigated is somewhat limited in terms of the logistics laid down for this study and is entirely the reason for this relatively high operating cost of the higher ranges. At this time, it is probably the most representative of the true off-road vehicles requiring the minimum or no support activity. The vehicle response time is therefore in keeping with the optimum ACV wheeled system.

5.2 COST ASPECTS OF THE OFF-ROAD ACV

Off-road ACV's are expensive. When compared to other surface vehicles, they are much more expensive in two important aspects: initial cost and fuel consumed. The requirement for sufficient installed power to lift the vehicle off the surface, even if this power is not used in much of the operation, means a large power plant. When a large proportion of the vehicle's weight is supported on the air cushion, fuel flow rates are high. Thus, over a period of hours, a large amount of fuel is used.

Because of the superior thrust/horsepower ratios which can be obtained by a wheel over those obtained from a propeller (at the very low speeds considered), the pure ACV must be eliminated from serious consideration because of its high installed propulsion power requirements. The added weight of the wheeled suspension system is paid for many times in the reduced power plant requirement, and fuel requirements are also proportionately reduced.

Although turbine engines are attractive from a weight and maintenance point of view, the much higher costs of turbine engines over those of reciprocating engines justified use of the latter in most overland vehicles. For the 20,000-pound wheeled ACV developed in this study, it was estimated that the 1,200-horsepower (total) turbine power plants would cost \$90,000, or 50 per cent of the total first cost. In

comparison with this, reciprocating engines of the same power rating (four at 300 horsepower each) would cost only \$30,000, a reduction in total vehicle cost of 33 per cent.

Maintenance costs of the ACV should be relatively low as a function of initial costs, particularly since cross-country operating shocks will to some extent be absorbed in the air cushion. Crew costs will not be high on the wheeled ACV's since operation will not be so complicated as to require aircraft-type crew skills. The speeds anticipated for off-road operations are low enough that automatic steering and obstacle-avoiding equipment would seem to be unjustified.

Operational requirements also influence the cost of ACV's. The combination of transportability and on-road size constraints, and the requirement for clearance of obstacles, defines a vehicle with very high cushion pressure and corresponding high power requirements. Again, gradability is a critical element, since installed propulsion power is directly proportional to the per cent grade which the vehicle must "hold". Because of this, the 60 per cent grade requirement is beyond reason for ACV's, and the 30 per cent grade requirement is always the determining factor in sizing the power plant.

Operational restraints of the logistics mission itself influence costs. In the cost/effectiveness analysis of the preceding chapter, the off-road ACV was assumed to be operated in a manner similar to other surface vehicles. The load/unload time associated with truck operations penalizes the higher speed capability of the ACV so that little is gained thereby. On the other hand, the necessity of maintaining center of gravity within small limits (about 1 foot fore and aft), requires careful management of cargo loading operations.

Range has a significant influence on costs. For the pure ACV, this influence is so pronounced as to severely limit the range payload capabilities of the vehicle. The wheeled ACV has a flatter range-payload slope, as seen in Figure 15. Even so, at ranges on the order of 100 miles, ACV costs are nearly the same as those of helicopters. Below 50 miles, the ACV shows up better; and in ranges of about 20-50 miles, its operating costs are optimized.

5.3 THE ROLE OF THE ACV IN THE OFF-ROAD LOGISTICS MISSION

As a result of this study, the potential role of the off-road ACV can be more clearly defined. It should be clearly recognized from the preceding analysis that the off-road ACV will have wheels. Configured in this manner, the vehicle characteristics would be as follows:

The most favorable operating ranges are between 20 - 50 miles.

The most advantageous operating environments are those where conventional vehicles are bogged down in mud, swamps, or unbridged streams. These segments of the assumed mission environment (Table 1), segments 3, 5, and 9, cover 20 per cent of the mission distance; in the environmental classification Tropical (wet), they cover 35 per cent. This may be a clue toward advantageous geographic applications.

Favorable operations for ACV's are those where response time is important and where engineer support can not be readily applied. Emergency resupply of forward units and support of irregular forces might be two such operations.

One of the most significant aspects of the off-road ACV is the potentiality of radically modifying off-road logistics concepts; namely, by using waterways as the LOC rather than considering them as obstacles. The ACV has capability for high-speed operation over water, certainly higher than in any of the overland environments. The application of ACV's to waterway supply routes would provide rapid (and inexpensive, relative to trucks operated cross country) resupply of forward areas. This aspect (only touched on here) may very well be of much greater significance than all of the off-road logistics operations discussed in this study. In fact, it is worthy of a relatively stronger research effect because of the possibility of a real breakthrough in military logistics concepts.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The ACV as a Logistic Off-Road Carrier

Within the framework of the assumed environment and mission, the use of an air cushion vehicle as an Army logistics carrier in off-road conditions, offers some advantage over other concepts although by comparison to trucks, its over-all cost is high.

It is also considered that in a great number of limited war applications, where environment, delicacy of payload, and vehicle service life are important parameters, the ACV may be the only contender. However, it should be carefully noted that the ACV, when performing in an "off-road" mission, cannot use its best speed to obtain a satisfactory degree of operating economy. Confined to normal "off-road" speeds of 5 to 15 miles per hour, it will be an expensive vehicle to operate. By using inland waterways and open grasslands whenever possible, the ACV in many circumstances could well be a vital part of the Army's off-road logistic carrier force. With this discussion in mind, the following conclusions may be drawn:

Mobility

The ACV provides mobility in swamps, water areas, and severe muddy conditions superior to that of other off-road Army logistic vehicles.

Maneuverability

General application of ACV's to overland logistic operations requires incorporation of wheels to provide adequate maneuvering control and satisfactory economic operation.

On-Road Effects

Constraints of "on-road" operations require sizing of the "off-road" ACV, which leads to severe effects on economy of operation.

Off-Road Effects

Constraints of overland operations reduce the average speed of the ACV to a point where the superior mobility characteristics are offset by high cost of operation.

Power-Plant Effects

ACV's configured for overland operations should employ reciprocating engines in order to reduce the high cost of the vehicle.

Areas of Use

The relative advantage of ACV's over other surface vehicles is greatest in tropical wet environments, as characterized by seasonal heavy rains, swamps, and extensive inland waterways.

Optimum Size

The optimum off-road logistic air cushion carrier will have a gross weight of 10 tons, a useful load of 4-1/2 tons, and a length of 30 feet.

Optimum Mission Characteristics

Low-volume, quick-response, short-duration missions are ideally suited to air cushion vehicle operations.

The Air Cushion Trailer (ACT)

The use of air cushion trailers, drawn by conventional "off-road" vehicles in the "off-road" logistics mission, offers definite advantages over conventional trailers where terrain prohibits their use. The high costs associated with the ACT, however, impose severe restrictions, unless payload sensitivity is a requirement. Based on the results of the section covering the optimization of air cushion trailers, the following conclusions have been formulated.

Optimization Techniques

Within the limitation imposed on the maximum allowable overall dimensions, techniques have been developed which provide an optimum ACV in terms of payload, power required, and cost.

Optimum ACT

Based on lowest cost considerations, an optimum ACT would have a gross weight of 2-1/2 tons, and a useful load of 1-1/8 tons distributed over the payload area at 25 - 30 psf. The vehicle would be powered by reciprocating engines and for control purposes would be fitted with wheels carrying 10 per cent of the gross weight.

Break Angle

The break angle of the optimum ACT will be smaller than those associated with conventional trailers.

Costs

It is considered that the high costs of the ACT configured to meet the requirements of this study place it in the category of vehicles with very limited application to the Army's off-road logistics mission.

6.2 RECOMMENDATIONS

As a direct outcome of this study, the following recommendations are in support of the preceding conclusions:

Further Studies

1. In order to provide a firm basis for the use of wheeled ACV's, it will be necessary to evaluate past and current military operations in order to determine the frequency of low-volume, quick-response, short-duration missions.
2. To support the preliminary technique used in this study to evaluate the performance of wheels at various off-loadings, it will be necessary to obtain more experimental evidence in order to complete the general analysis technique.

3. For the carriage of payloads with great sensitivity, acceleration values should be estimated over a wide range of terrains and performance.

4. The potential of the ACV as an inland-waterway logistics carrier should be thoroughly investigated. This study should include a necessary revision of logistics concepts and nuclear geography intelligence.

5. Based on the above, it is highly recommended that the development of a wheeled ACV be undertaken at the earliest possible time. Although extensively limited from a payload standpoint, the GEMINI type vehicle could easily be the first step in this direction.

6. At this time, the development of an air cushion trailer seems less than desirable due to the high attendant costs. However, when terrain or payload sensitivity is of paramount importance, these costs may well be warranted.

CHAPTER VII

PERFORMANCE AND COST PARAMETERS OF A FAMILY OF AIR CUSHION TRAILERS

7.1 GENERAL CONSIDERATIONS

This part of the report is concerned with the optimization of an air cushioned trailer capable of being towed by a variety of conventional Army type vehicles.

For the preparation of this brief review, the trailer is expected to be used on "off-the-road" logistic missions. Therefore, the trailer should be capable of meeting requirements regarding size, speed, gross weight, payload, route stability, cost, economy of operation, and other items of performance consistent with this mission.

Sizes

The "Mover Report", in its recommendations, defines a family of trailers, with regard to sizes and cargo capacity, for general and standardized uses by the different U.S. Army corps, Reference 34.

As a reference and also as a goal in this optimization study, Table 55 summarizes the characteristics of this family of trailers.

TABLE 55 PROPOSED FAMILY OF TRAILERS		
Trailer	Rated tons	Dimensions (l x w) ft.
1	1/4	6 x 5
2	1-1/4	9 x 6
3	2-1/2	9 x 6
4	5	15 x 8
5	10	23 x 8

The requirements set forth in this table do not fix a constraint in the characteristics of the optimized trailer, with the exception of the

maximum width, but sets a pattern with regard to the sizes of vehicles the U. S. Army would like to standardize.

With this in mind, a maximum width of 8 feet has been established for this study. Considering the possible use of side wheels to provide side-force control, the maximum width can be estimated at 7.20 feet. Since the power required is a function of the jet length, and since jet length is a function of the planform, it is considered that the limiting case would be a rectangle with a length-to-width ratio of 2:1, thus fixing the maximum dimensions as follows:

$$\begin{aligned} b &= 14.40 \text{ feet} \\ w &= 7.20 \text{ feet} \\ S_b &= 103.68 \text{ feet}^2 \end{aligned}$$

Disposable Load

In keeping with current ACV technology, it has been assumed that the disposable load for the trailer ACV will be 50 per cent of the gross weight. This ratio is considered extremely conservative, as the saving in empty weight due to the lack of a propulsion system will be offset by the need of wheels for road holding in the presence of side forces, and the need for a rugged structure.

Operating Height

It is considered that the hard structure should be located 2 feet above the ground, with a flexible extension providing a vehicle clearance height of 3 inches in order to conserve lift power. Based on Saunders-Roe and Vickers data, it is considered that 3 inches is acceptable in order to avoid dragging and excessive wear of the flexible extensions.

Speed and Range

With no means for propulsion, it is anticipated that this vehicle will be towed in the "off-the-road" missions by slow-moving vehicles with speeds no higher than 15 miles per hour over ranges up to 100 miles.

Ruggedness

Considering the environment in which the machine will work, plus the fact that it will be towed and operated by people inexperienced in this type of trailer, the primary structure should be designed to withstand the normal environment for Army trailers. The weight of the structure per square foot of cushion area should therefore be in keeping with this philosophy.

Equipment

No special trailer-borne equipment is considered, with the exception of the engine remote controls.

Road Holding

As mentioned under disposable load, the use of wheels has been considered in order to avoid heavy side loads on the towing vehicle due to side winds and centrifugal force during turns. It has been assumed that these wheels should be capable of taking up to 10 per cent of the gross weight considered in the running condition. In the static position, during loading and unloading, the wheels (against stops) will maintain normal truck heights.

7.2 OPTIMIZATION OF THE AIR CUSHION TRAILER

Following the requirements for size and payload set in the preceding chapter, a family of air cushion trailers can be tentatively defined. Table 56 is a summary of such a family.

TABLE 56 TENTATIVE FAMILY OF AIR CUSHION TRAILERS				
Trailer	Gross weight	Payload	Max. dimensions ft. x ft.	Cushion pressure lb/ft ²
1	1,000	500	8 x 4	36.8
2	2,500	1,250	10 x 5	58.8
3	5,000	2,500	12 x 6	81.7
4	10,000	5,000	12 x 6	163.4
5	20,000	10,000	16 x 8	183.8
6	40,000	20,000	16 x 8	367.6

From this table, it can be seen that, with the exception of the first three trailers, the cushion pressure values are much higher than those used in current air cushion vehicles. Also, it is obvious that the sizes of trailers cannot be fixed arbitrarily from geometric considerations above. The optimum size and cushion pressure must be established for each payload or gross weight by investigating the effect of a number of interdependent variables on governing parameters.

Governing Parameters

The design of any ACV is governed by a number of different parameters. For convenience, they may be represented in nondimensional form as functions of the cushion pressure. They are:

Structural Weight

The structural weight can be expressed by the equation:

$$W_s = P \times \text{cushion area,}$$

where

$$P = \text{structural weight per square foot of cushion area,}$$

or in nondimensional form,

$$\frac{W_s}{W_G} = \left(\frac{P}{S_b} \right)$$

This is true when the value of P has been set. Current values for this parameter vary between 7 and 25 p.s.f., depending on the load and safety factors used. Assuming that the unit structural weight will vary with the cushion pressure, the following equation has been developed:

$$\frac{W_s}{W_G} = \frac{2.36}{\left(\frac{W_G}{S_b} \right)^{0.481}} \quad (1)$$

It is recognized that the use of this equation will produce a very rugged machine; but nevertheless, it is in agreement with the values of the TRECOM Report No. TCREC Tech. Rep. 62-41. This equation is plotted in Figure 35 and 36 on nonlogarithmic and logarithmic paper respectively.

Disposable Load

The gross weight of an ACV is comprised of:

$$W_G = \underbrace{W_{PL} + W_F}_{W_{DL}} + \underbrace{W_S + W_{PP}}_{W_E} \quad (2)$$

where W_G = gross weight (lb)
 W_{PL} = payload (lb)
 W_F = fuel weight (lb)
 W_S = structure weight (lb)
 W_{PP} = power-plant weight (lb)
 W_E = empty weight (lb)
 W_{DL} = disposable load (lb)

In nondimensional form and as a function of the cushion pressure:

$$\frac{W_{DL}}{S_c} = \frac{W_G}{S_b} \left(\frac{1 - W_E}{W_G} \right) \quad (3)$$

where S_b = cushion area.

Based on this expression, a family of curves for different load densities can be obtained. By combining these curves with those for the structural weight (Figure 37), it is possible to define, for each cushion pressure, that portion of the gross weight which is

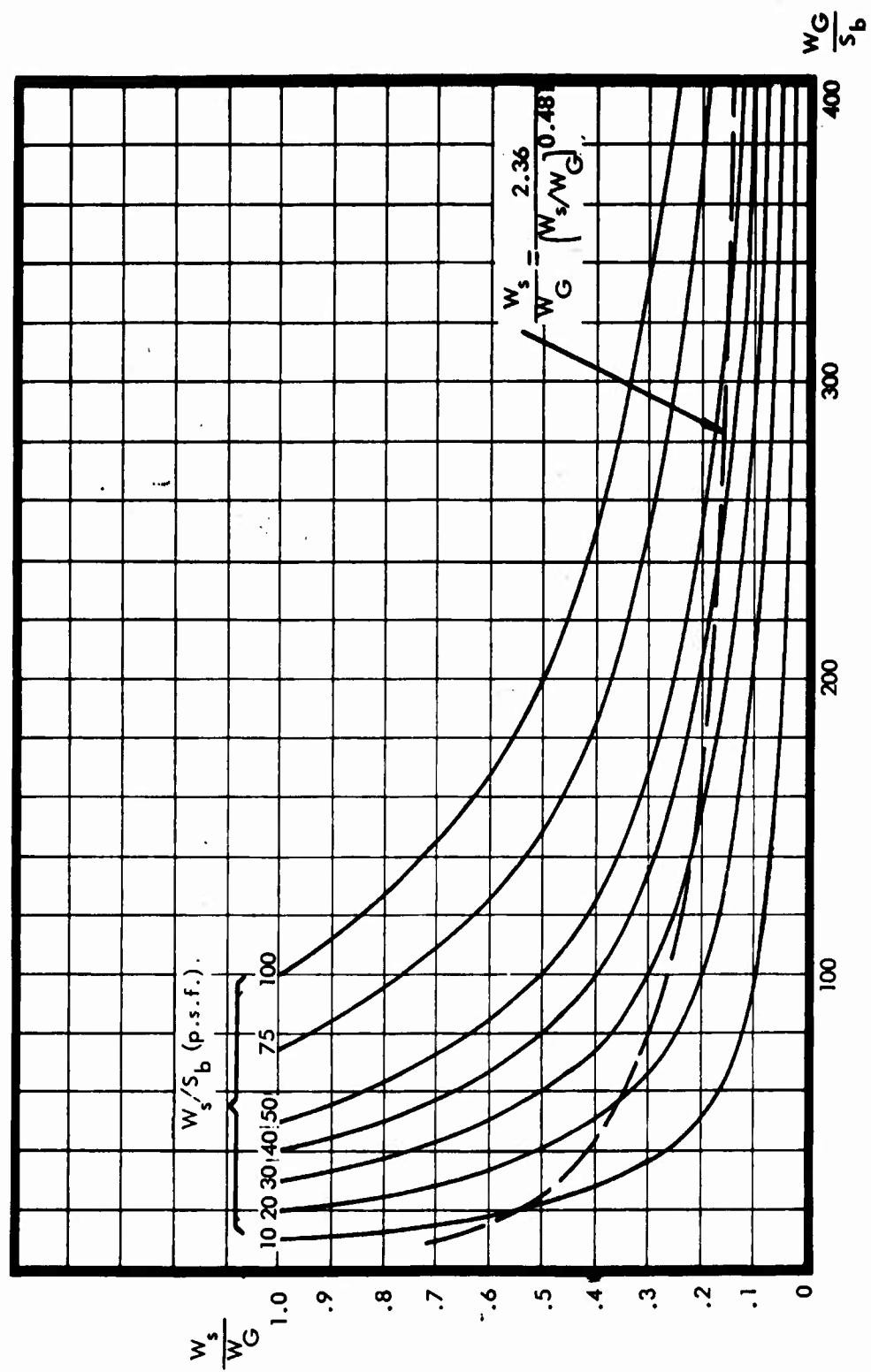


Figure 35. $\frac{W_s}{W_G}$ vs. $\frac{W_G}{S_b}$

$$\frac{W_s}{W_G} = 2.36 \times \left\{ \frac{W_G}{S_b} \right\}^{-0.481}$$

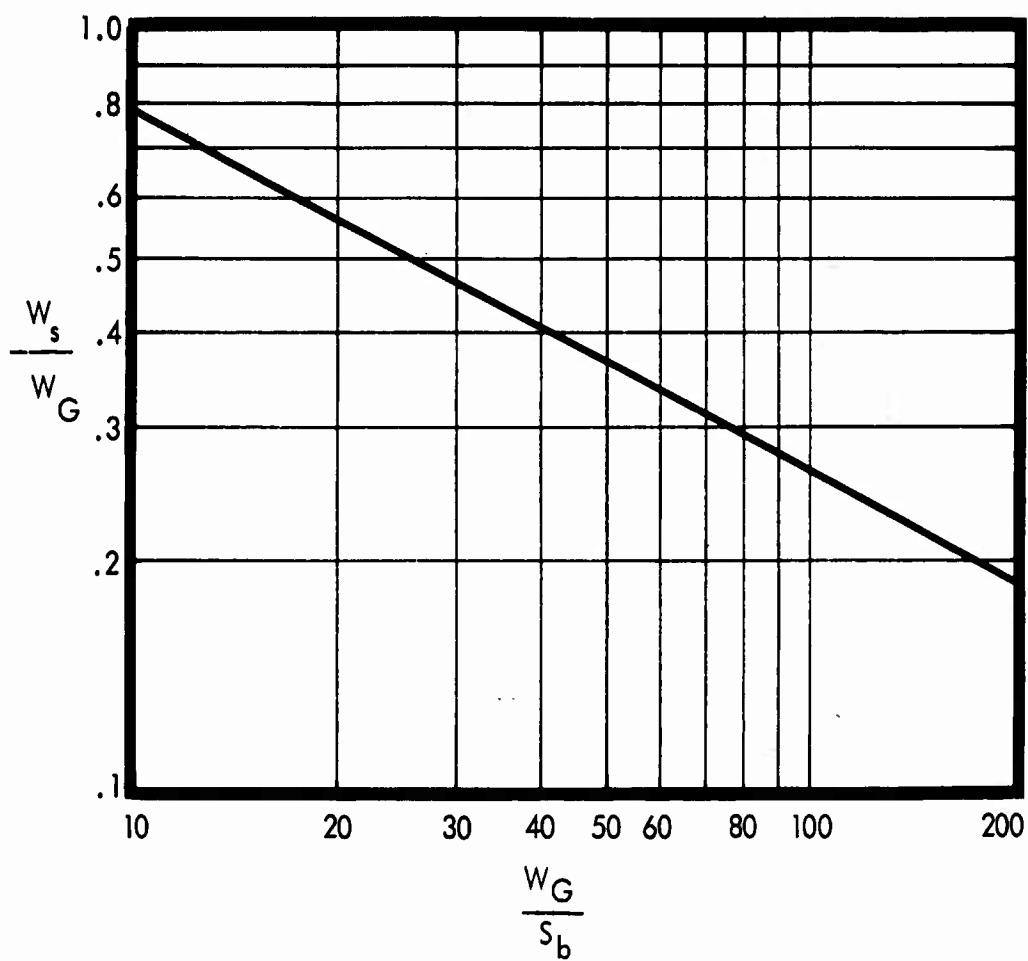


Figure 36. $\frac{W_s}{W_G}$ vs. $\frac{W_G}{S_b}$

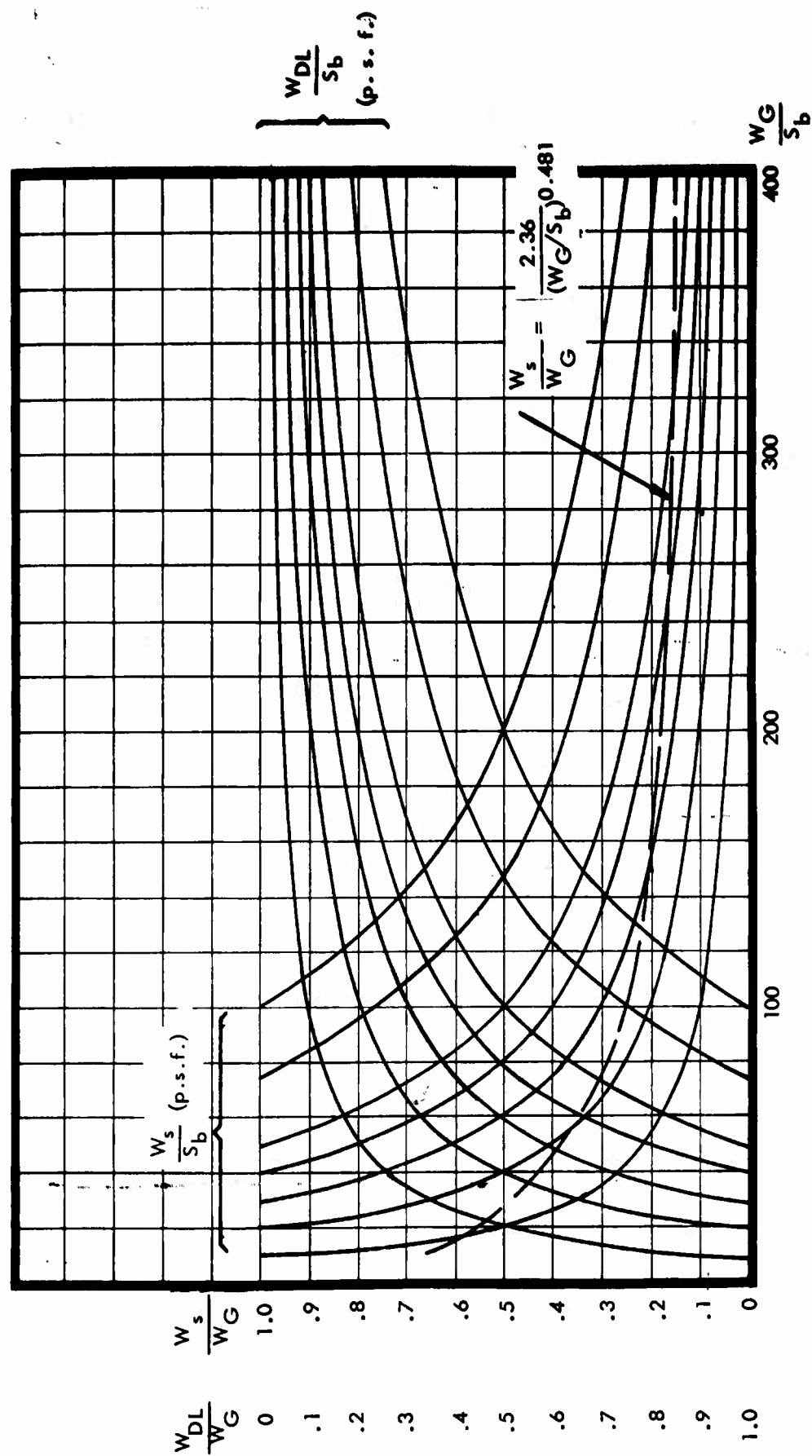


Figure 37. $\frac{W_{DL}}{W_G}$, $\frac{W_s}{W_G}$ vs. $\frac{W_G}{S_b}$

available for the power plant at a given cargo density. It should be noted that the result is not necessarily defining the optimum configuration.

Power Plant

Power Required. Assuming a 0.60 efficiency factor for the power-plant system, the SHP requirements for a circular planform ACV are:

$$\text{SHP} = 5.44 \times \sqrt{W_G} \times \frac{W_G}{S_b} \times h \quad (4)$$

where

$$W_G = \text{tons}$$

$$\frac{W_G}{S_b} = \text{lb/ft}^2$$

$$h = \text{ground clearance in feet.}$$

With all the parameters in pounds and correcting for a rectangular planform of ratio 2:1:

$$\text{SHP} = 0.1475 \sqrt{W_G} \times \frac{W_G}{S_b} \times h \quad (5)$$

This expression has been plotted in Figure 38 for $h = 0.25$ foot.

Power-Plant Weight. The unit weight of power plants suitable for trailer use will vary considerably. For powers under 500 sp, it has been assumed that a mean average of the power plants examined will satisfy study requirements. Accordingly, a value of 2.5 lb/shp has been selected.

Assuming, from a cost standpoint, that only reciprocating engines will be used, it is necessary to apply a factor of 0.60 (cruising condition).

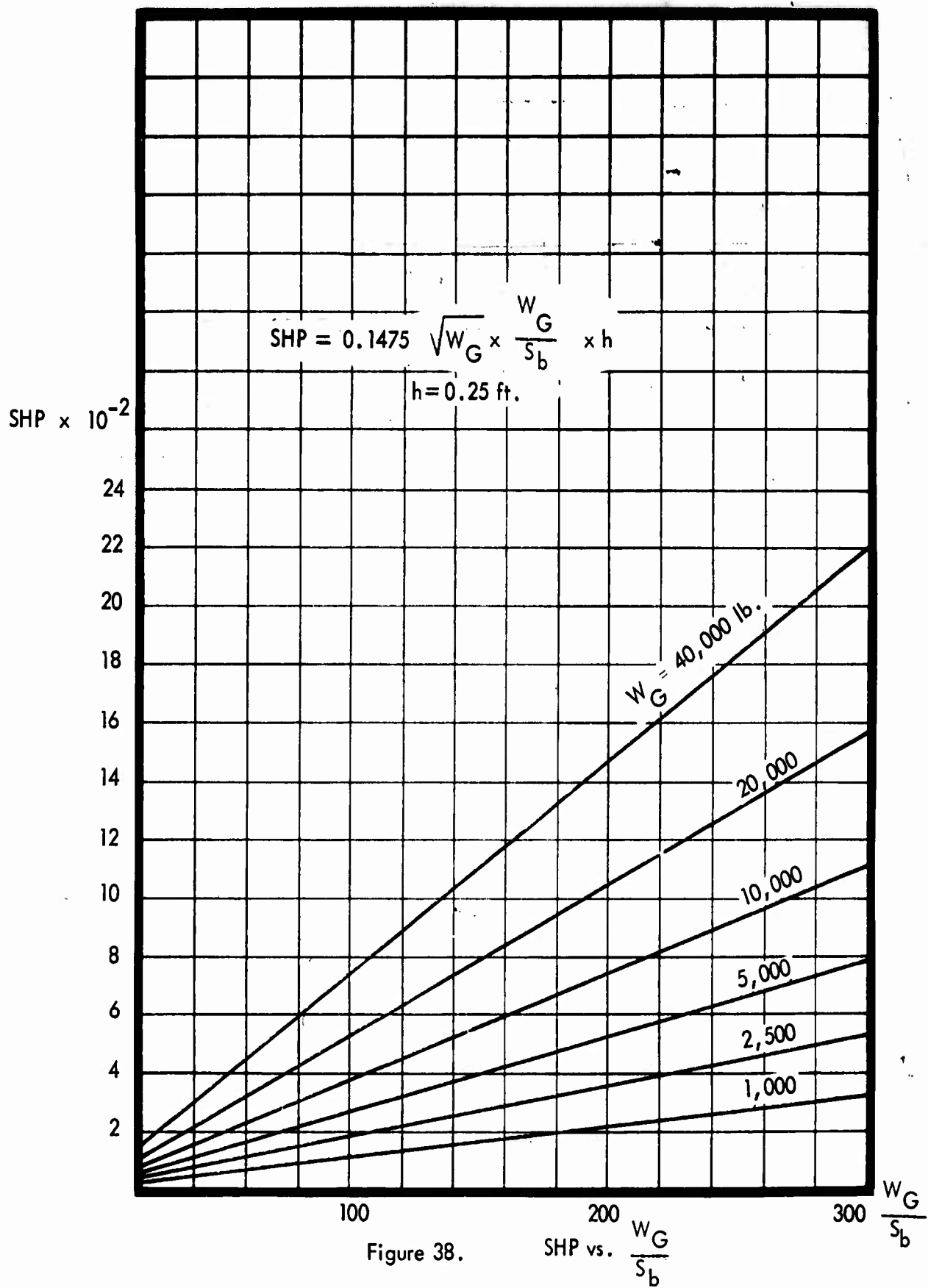


Figure 38.

Thus the weight of the installed power plant can be given by:

$$W_{PP} = 2.5 \times \frac{SHP}{0.6} \quad (6)$$

or

$$W_{PP} = 0.615 \sqrt{W_G} \times \frac{W_G}{S_b} \times h \quad (7)$$

and in nondimensional form:

$$\frac{W_{PP}}{W_G} = 0.615 \times \frac{1}{\sqrt{W_G}} \times \frac{W_G}{S_b} \times h. \quad (8)$$

Fuel Weight. To decide on the advisability of carrying the fuel required on board the trailer, as well as for comparative cost purposes, it is necessary to determine the fuel requirements. For the 100-mile range and a top speed of 15 miles per hour, and considering an SFC of 0.5 lb/hp/hr,

$$W_F = SHP \times SFC \times \frac{\text{Range}}{\text{Speed}}. \quad (9)$$

Then, for the study conditions:

$$W_F = 3.3 SHP \quad (10)$$

or

$$\frac{W_F}{W_G} = 0.487 \times \frac{1}{\sqrt{W_G}} \times \frac{W_G}{S_b} \times h. \quad (11)$$

Methods of Optimization

With the vehicle's parameters in nondimensional form related to the cushion pressure, it is possible to optimize in a dimensional form a family of air cushion trailers.

This optimization has been carried out for different gross weights and for the following four methods of optimization:

<u>Method</u>	<u>Condition</u>
1	$\left(\frac{W_{DL}}{W_G} \right)_{\max}$
2	$\left(\frac{W_{DL}}{SHP} \right)_{\max}$
3	$S_b = \text{constant}$
4	$\frac{d}{dP_b} \left(\frac{W_{PP}}{W_G} \right) = \frac{d}{dP_b} \left(\frac{W_E}{W_G} \right)$

The results of applying these four methods are tabulated in a single table (Table 57) for ease of comparison. A discussion of each method follows.

Method I $\left(\frac{W_{DL}}{W_G} \right)_{\max}$

Solving equations (7) and (8) for $h = 0.25$ and for W_G from 1,000 to 20,000 pounds and plotting the results in Figure 39, it can be seen

what cushion pressure is required to satisfy $\frac{W_{DL}}{W_G}_{\max}$ This

method will render, for each gross weight, the optimum size of vehicle. However, it can be seen from Table 57 that the ratio of payload to horsepower is low, based on the acceptable load density.

This method also shows a trend for higher $\frac{W_{DL}}{W_G}$ and $\frac{W_{DL}}{W_{PP}}$ as the machine becomes heavier; however, the size of cushion area exceeds the limits set in Section 7.1 for machines weighing between 5,000 and 10,000 pounds.

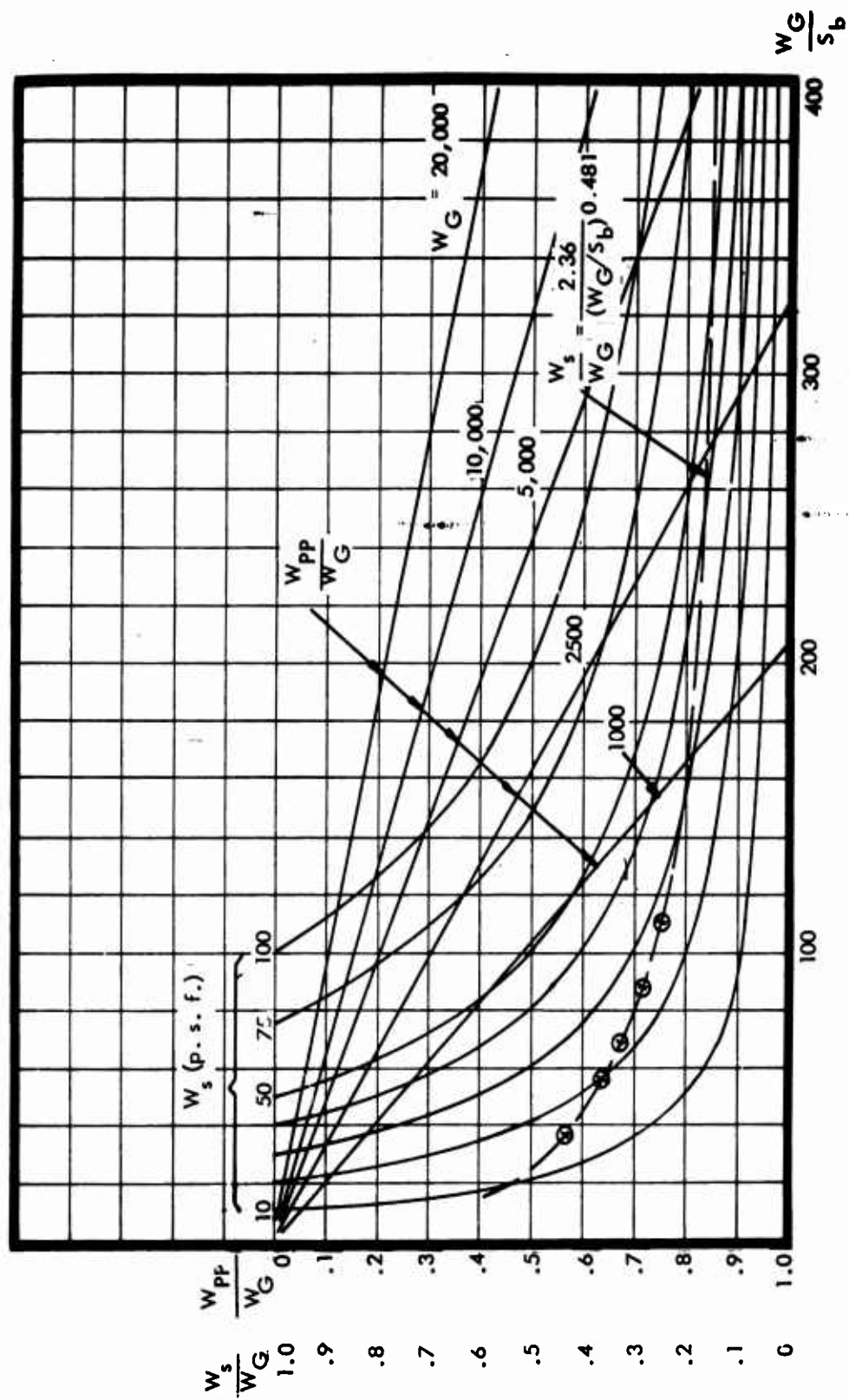


Figure 39. $\frac{W_s}{W_G}$ vs. $\frac{W_{PP}}{W_G}$ vs. $\frac{W_G}{S_b}$ (h 0.25 ft.)

Method 2 $\frac{W_{DL}}{SHP} \text{ max}$

Keeping in mind that a reduction in power required will also bring a reduction in fuel requirements, this approach would appear to provide an optimum solution:

Writing $\frac{W_{DL}}{W_{PP}} = \frac{W_G}{W_{PP}} - \frac{W_s}{W_{PP}} - 1$

and substituting

$$\frac{W_{DL}}{W_{PP}} = \frac{W_G}{0.617 \times P_c \times h} - \frac{2.36}{0.617 \times h \times P_c} \frac{W_G}{0.481} - 1$$

for maximum

$$\frac{W_{DL}}{W_{PP}} \quad P_c \approx 14 \text{ p.s.f.}$$

Tabulating again for different gross weights and this value of the cushion pressure (Table 57), it is found that as in Method 1, the heavier machine is the most efficient and that there is a definite gain

in the ratio $\frac{W_{DL}}{HP}$ with a same deterioration of the ratio $\frac{W_{DL}}{W_G}$ which

is rising with the increase in gross weight. With the exception of the lightest, all vehicles exceed the maximum allowable dimensions, with corresponding low load densities.

Method 3 $S_b = \text{constant}$

The values for the different gross weights are tabulated in Table 57, showing that all the trailers considered meet the dimensional require-

ments. By this method, the ratio $\frac{W_{DL}}{HP}$ reverses the trend shown in Methods 1 and 2, reaching approximately the same values for

$\frac{W_{DL}}{W_G}$ and $\frac{W_{DL}}{W_{PP}}$ as in Method 1 for the 5,000 pounds gross weight example.

$$\text{Method 4} \quad \frac{d}{dP_b} \frac{W_{PP}}{W_G} = - \frac{d}{dP_b} \frac{W_E}{W_G}$$

From the analysis of the values shown in Table 57 for Methods 1, 2, and 3, it is evident that the optimum machine will be found for values of the cushion pressure in between those for Methods 1 and 2 for each gross weight. To find this values, the rate of change of the ratio $\frac{W_{PP}}{W_G}$ is equated to the rate of change of $\frac{W_E}{W_G}$. The following equation will provide values of the cushion pressure, as a function of the gross weight for this condition.

$$P_b = \left[3.69 \left(W_G \right)^{1/2} \right]^{1.481}$$

Figure 40 presents a graphical solution of this equation.

The value for the different parameters using this approach is tabulated also in Table 57.

Comparing these values with those obtained in Methods 1, 2, and 3,

both ratios $\frac{W_{DL}}{W_G}$ and $\frac{W_{DL}}{HP}$ show a marked improvement, as well

as acceptable values for the load density. But, again, only two machines, the small ones, meet the size requirements.

Using any one of these four approaches, it is possible to define the optimum machine with regard to its physical characteristics; however, this will not necessarily define the most efficient machine, in terms of the lowest cost/ton/mile. The following section, using the four methods, determines the cost/effectiveness of each of the five vehicles considered.

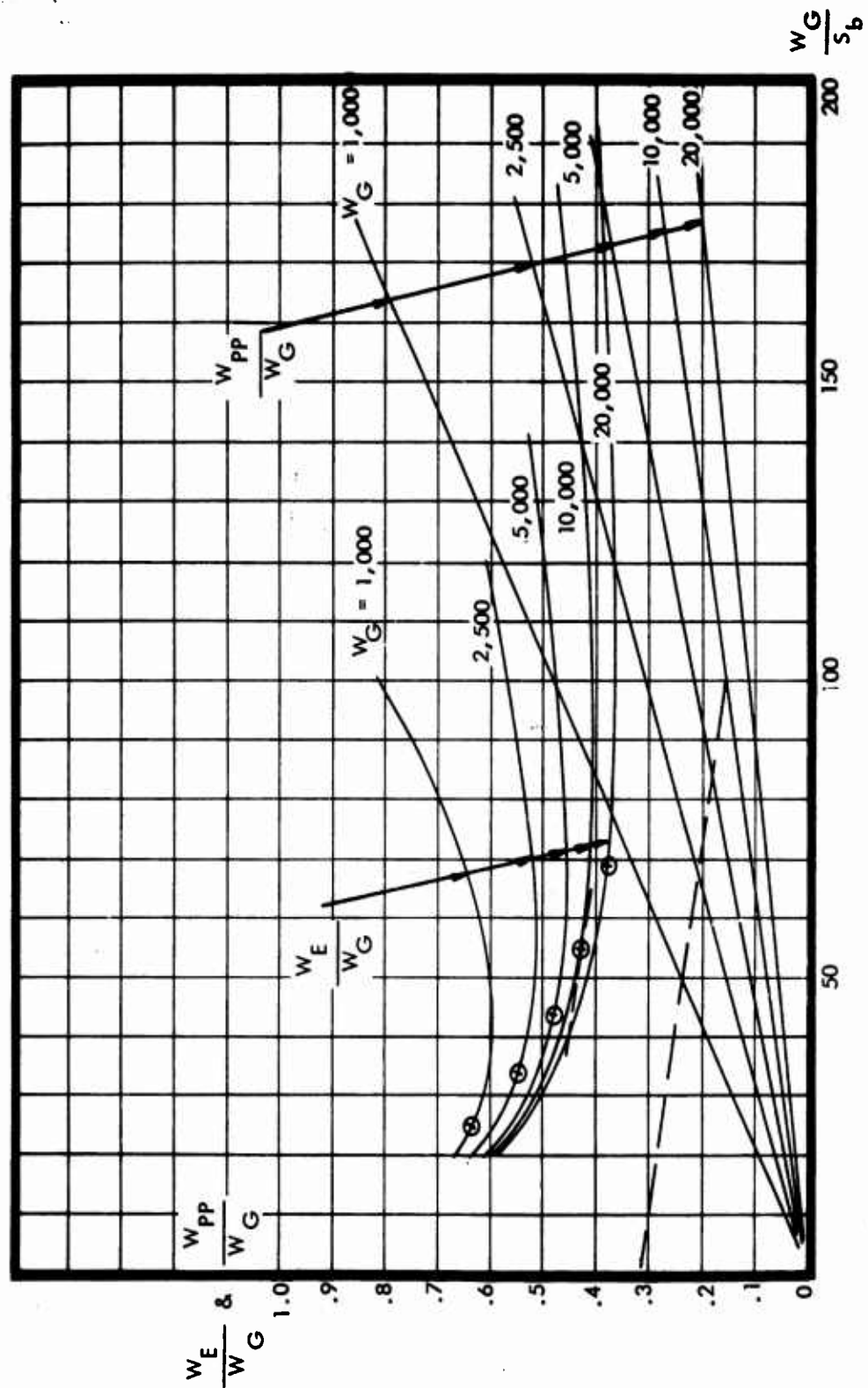


Figure 40. $\frac{W_E}{W_G}$ vs. $\frac{W_{PP}}{W_G}$ ($h = 0.25$ ft.)

TABLE 57
METHODS OF OPTIMIZATION

Method	W_G lb.	$W_{G/S}$ lb/ft ²	S_b ft ²	S ft ²	b x w ft x ft
1	1,000	38.0	26.3	31.1	7.88 x 3.94
	2,500	54.0	46.3	54.5	10.26 x 5.13
	5,000	69.0	72.5	85.4	13.08 x 6.54
	10,000	87.0	115.0	135.4	15.84 x 7.92
	20,000	110.0	181.5	214.0	20.70 x 10.35
2	1,000	14	71.43	84.0	12.96 x 6.48
	2,500	14	178.6	210.0	20.50 x 10.25
	5,000	14	357.1	420.0	28.94 x 14.47
	10,000	14	714.3	840.0	40.80 x 20.40
	20,000	14	1,428.6	1,680.7	37.20 x 28.60
3	1,000	11.3	88.13	103.68	14.40 x 7.20
	2,500	28.4	88.13	103.68	14.40 x 7.20
	5,000	56.8	88.13	103.68	14.40 x 7.20
	10,000	113.6	88.13	103.68	14.40 x 7.20
	20,000	226.9	88.13	103.68	14.40 x 7.20
4	1,000	24.7	40.40	47.53	9.74 x 4.87
	2,500	33.8	73.96	87.01	13.20 x 6.60
	5,000	43.7	114.40	134.59	16.42 x 8.21
	10,000	54.0	185.00	217.60	20.84 x 10.42
	20,000	68.5	291.97	343.50	26.20 x 13.10

TABLE 57 (continued)
METHODS OF OPTIMIZATION

Method	W_S/W_G	W_S lb.	W_S/S_c lb/ft ²	HP _{req}	HP _{inst}
1	0.411	411	15.6	44.3	73.8
	0.349	873	18.9	99.6	166.0
	0.307	1,513	21.1	180.0	300.0
	0.276	2,760	22.1	321.0	535.0
	0.246	4,920	27.1	574.0	956.0
2	0.663	663	9.28	16.3	27.2
	0.663	1,658	9.28	25.8	43.0
	0.663	3,316	9.28	36.5	59.2
	0.663	6,630	9.28	51.7	86.2
	0.663	13,260	9.28	73.2	122.0
3	0.735	735	8.32	13.15	21.9
	0.472	1,180	13.36	52.45	87.3
	0.338	1,690	19.15	184.40	247.0
	0.244	2,435	27.60	419.00	698.0
	0.179	3,580	40.62	1,183.05	1,977.8
4	0.505	505.00	12.50	28.80	48.00
	0.435	1,087.50	14.70	62.36	103.93
	0.384	1,920.00	16.78	114.00	190.09
	0.347	3,470.00	18.75	199.13	331.90
	0.309	6,180.00	21.17	357.66	596.08

TABLE 57 (continued)
METHODS OF OPTIMIZATION

Method	$W_{PP_{inst}}$ lb.	W_{PP/W_G}	W_{DL} lb.	W_{DL/W_G}	$W_{DL/HP}$ lb/HP
1	184.5	0.185	404.0	0.404	9.1
	415.0	0.166	1,213.0	0.485	12.9
	750.0	0.150	2,720.0	0.543	15.1
	1,340.0	0.134	5,900.0	0.590	18.4
	2,390.0	0.120	12,690.0	0.634	22.1
2	65.5	0.066	271.0	0.271	16.6
	107.5	0.043	735.0	0.294	28.5
	148.0	0.030	1,535.0	0.307	41.0
	215.5	0.022	3,150.0	0.315	61.0
	305.0	0.015	6,435.0	0.322	87.9
3	54.8	0.055	210.0	0.210	16.0
	218.0	0.087	1,105.0	0.441	21.1
	617.0	0.123	2,690.0	0.539	18.1
	1,745.0	0.175	5,810.0	0.581	13.9
	4,929.5	0.247	11,480.0	0.574	9.7
4	120.00	0.120	375.0	0.375	13.02
	259.83	0.104	1,152.5	0.461	18.48
	475.23	0.095	2,605.0	0.521	22.84
	829.80	0.083	5,700.0	0.570	28.60
	1,490.20	0.075	12,320.0	0.616	34.45

TABLE 57 (continued)
METHODS OF OPTIMIZATION

Method	W_{DL/S_L} lb/ft ²	W_E lb.	W_F lb.	W_{PL} lb.	W_{PL}/W_G
1	13.0	596	146.2	257.8	0.258
	23.6	1,288	329.0	884.0	0.354
	31.8	2,280	594.0	2,126.0	0.425
	43.6	4,100	1,060.0	4,840.0	0.484
	59.3	7,310	1,894.0	10,796.0	0.540
2	3.23	7,290	53.8	210.2	0.210
	3.50	1,766	85.2	649.8	0.260
	3.65	3,464	120.5	1,414.5	0.283
	3.75	6,846	170.6	2,979.4	0.298
	3.83	13,565	241.6	6,193.4	0.310
3	2.02	790	43.4	166.6	0.167
	10.65	1,398	173.0	932.0	0.373
	25.90	2,307	488.0	2,202.0	0.440
	57.0	4,180	1,375.0	4,435.0	0.444
	110.73	8,520	3,904.0	7,560.0	0.379
4	7.89	625.00	95.04	280.0	0.280
	13.25	1,347.33	205.79	946.7	0.379
	19.36	2,395.23	376.40	2,228.6	0.446
	26.20	4,300.00	657.10	5,042.9	0.504
	35.87	7,670.20	1,180.28	1,139.7	0.557

7.3 COST EFFECTIVENESS

To define the optimum trailer, it is necessary to estimate the cost/ton/mile. This is done in this study on a preliminary estimate basis, using the following simplifying assumptions:

1. Number of trailers built, $N = 100$
2. Vehicle life = 10,000 hours over a 3-year period
3. Complete power-plant cost, $C_{pp} = \$30/\text{hp}$
4. Structural cost, $C_s = \$7.3/\text{lb}$ (100 vehicles)
5. Research and development cost
 $C_{RD} = 0.1 C_I$ (initial cost)
6. No equipment cost is considered
7. Crew cost is not applicable
8. Gasoline cost, \$0.15/gallon (gasoline 6.2 lb/gallon)
9. Maintenance cost, $C_M = 0.5 C_I$ (over a 3-year period).

Initial Cost

$$C_I = 1.1 (30 \times \text{HP}_{\text{inst}} + 7.3 \times W_S)$$

Maintenance Costs

$$C_M = 0.5 \times C_I$$

Cost Per Hour of Operation

$$C_H = \frac{1.5 \times C_I}{10,000} + \frac{W_F \times 0.15}{6.6 \times 6.2}$$

Cost Per Ton-Mile

$$C_{TM} = \frac{C_H \times 2,000}{15 \times W_{DL}} \quad (\text{No fuel on board})$$

$$C_{TM} = \frac{C_H \times 2,000}{15 \times W_{PL}} \quad (\text{Fuel on board})$$

These equations are applied to each one of the vehicles considered and the results tabulated in Table 58 and plotted in Figures 41 and 42.

From these data, it is interesting to note that the most efficient machines are those optimized using Method 4. However, these are somewhat handicapped, as they exceed the maximum dimensions set in Section 7.1.

Within the maximum dimensions allowed, the optimum vehicle on a cost/ton/mile basis is the 5,000-pound-gross-weight vehicle, with or without the fuel on board. However, in the case when fuel is carried by the trailer, there is a very minor difference between the 5,000-pound and 10,000-pound-gross-weight vehicles. In the latter case, the limiting consideration is the size of the power plant required.

It should be noted also that the value of cushion pressure for the optimum configuration does not exceed 70 p. s. f.

On Figures 41 and 42, a dotted curve represents the vehicles having the maximum planform allowed by design considerations, and a family of such curves can be plotted for different size planforms. These figures show that, for each case, although an efficient vehicle can be designed, it either exceeds the required dimensions or its cost per ton-mile is high.

Tractive Force

The tractive force required for different slopes, as a function of the weight of the vehicles, is given by the equation:

$$F_T = W_G \times \sin \alpha.$$

TABLE 58
OPERATING COSTS OF FIVE ACT'S
USING FIVE METHODS OF OPTIMIZATION

W_G lb.	W_E lb.	W_{DL} lb.	W_F lb.	W_{PL} lb.	HP _{inst}
1,000	596	404	146.2	257.8	74
2,500	1,288	1,212	329.0	884.0	166
5,000	2,280	2,720	594.0	2,126.0	300
10,000	4,100	5,900	1,060.0	9,840.0	535
20,000	7,310	12,690	1,894.0	10,796.0	956
1,000	729	271	53.8	217.2	27
2,500	1,766	734	85.2	648.8	43
5,000	3,464	1,536	120.5	1,415.5	59
10,000	6,846	3,154	170.6	2,983.4	86
20,000	13,565	6,435	241.6	6,193.4	122
1,000	790	210	43.4	166.6	22
2,500	1,398	1,102	173.0	929.0	87
5,000	2,307	2,693	988.0	2,205.0	247
10,000	4,180	5,820	1,375.0	4,445.0	698
20,000	8,520	11,480	3,904.0	7,576.0	1,978
1,000	625	375	95.0	280.0	48
2,500	1,347	1,153	205.8	947.2	101
5,000	2,395	2,605	376.4	2,228.6	190
10,000	4,300	5,700	657.1	5,042.9	332
20,000	7,670	12,330	1,180.3	11,199.7	596

TABLE 58 (continued)
OPERATING COSTS OF FIVE ACT'S
USING FOUR METHODS OF OPTIMIZATION

C_E \$	C_{M_H} \$	C_{F_H} \$	C_{T_H} \$	\$/ton/mi. (W_{DL})	\$/ton/mi. (W_{PL})
6,069	0.91	0.54	1.45	0.48	0.75
12,488	1.87	1.21	3.08	0.33	0.47
22,186	3.33	2.18	5.51	0.27	0.35
39,818	5.97	3.89	9.86	0.22	0.27
70,382	10.56	6.94	17.50	0.18	0.22
6,222	0.93	0.20	1.13	0.56	0.69
14,029	2.15	0.31	2.66	0.48	0.54
28,581	4.29	0.44	4.73	0.41	0.45
56,084	8.41	0.63	9.04	0.38	0.40
110,504	16.58	0.89	17.47	0.36	0.38
6,625	0.99	0.16	1.15	0.73	0.92
12,356	1.85	0.63	2.48	0.30	0.36
21,722	3.26	1.79	5.05	0.25	0.31
42,588	6.39	5.04	11.43	0.26	0.34
94,015	14.10	14.31	28.41	0.33	0.50
5,640	0.85	0.35	1.20	0.43	0.57
12,163	1.82	0.75	2.57	0.30	0.36
21,691	3.25	1.38	4.63	0.24	0.28
38,817	5.82	2.41	8.23	0.19	0.22
69,296	10.39	4.33	14.72	0.16	0.18

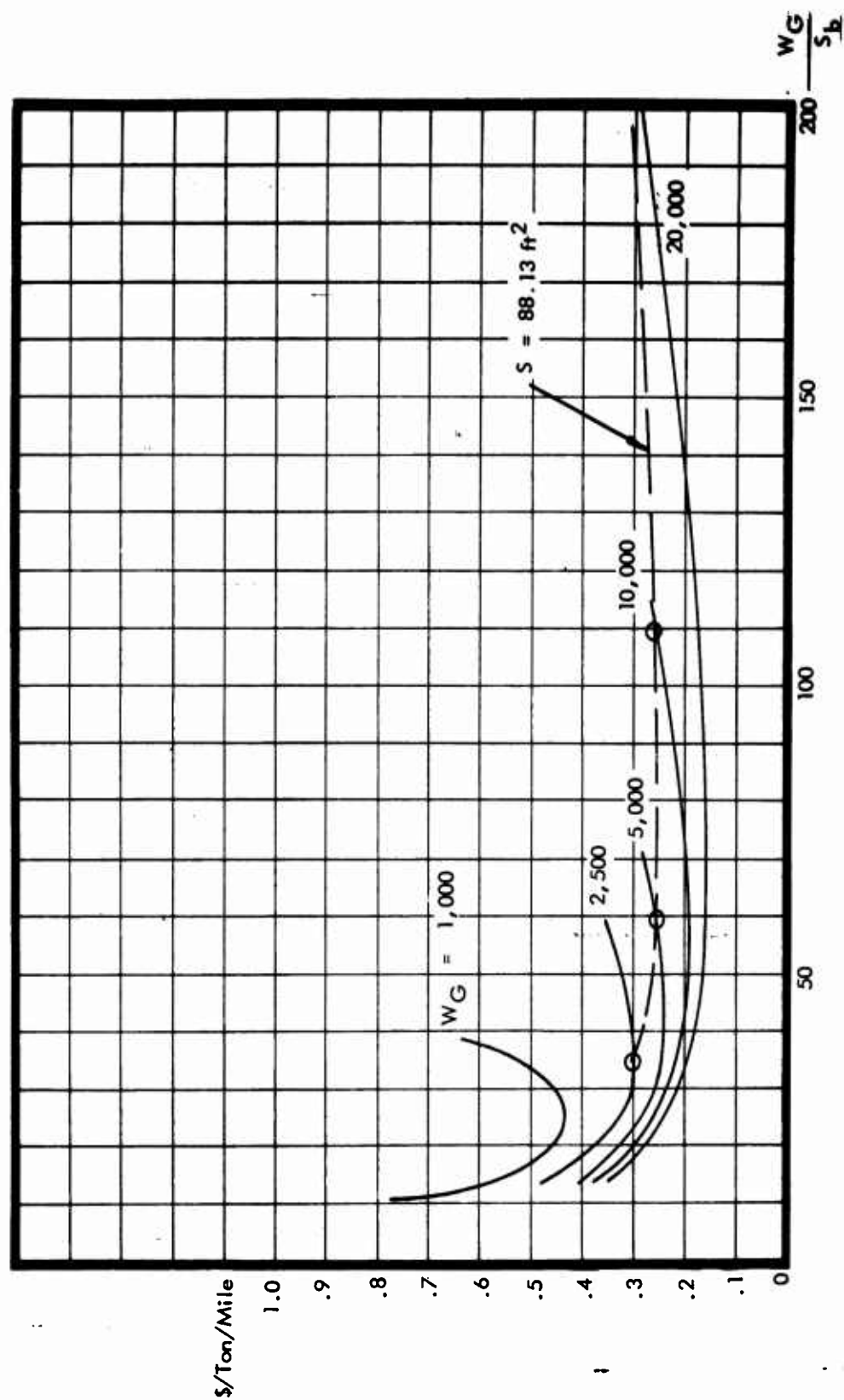


Figure 41. $\frac{W_G}{S_b}$ (Fuel out board) vs. $S/Ton/Mile$

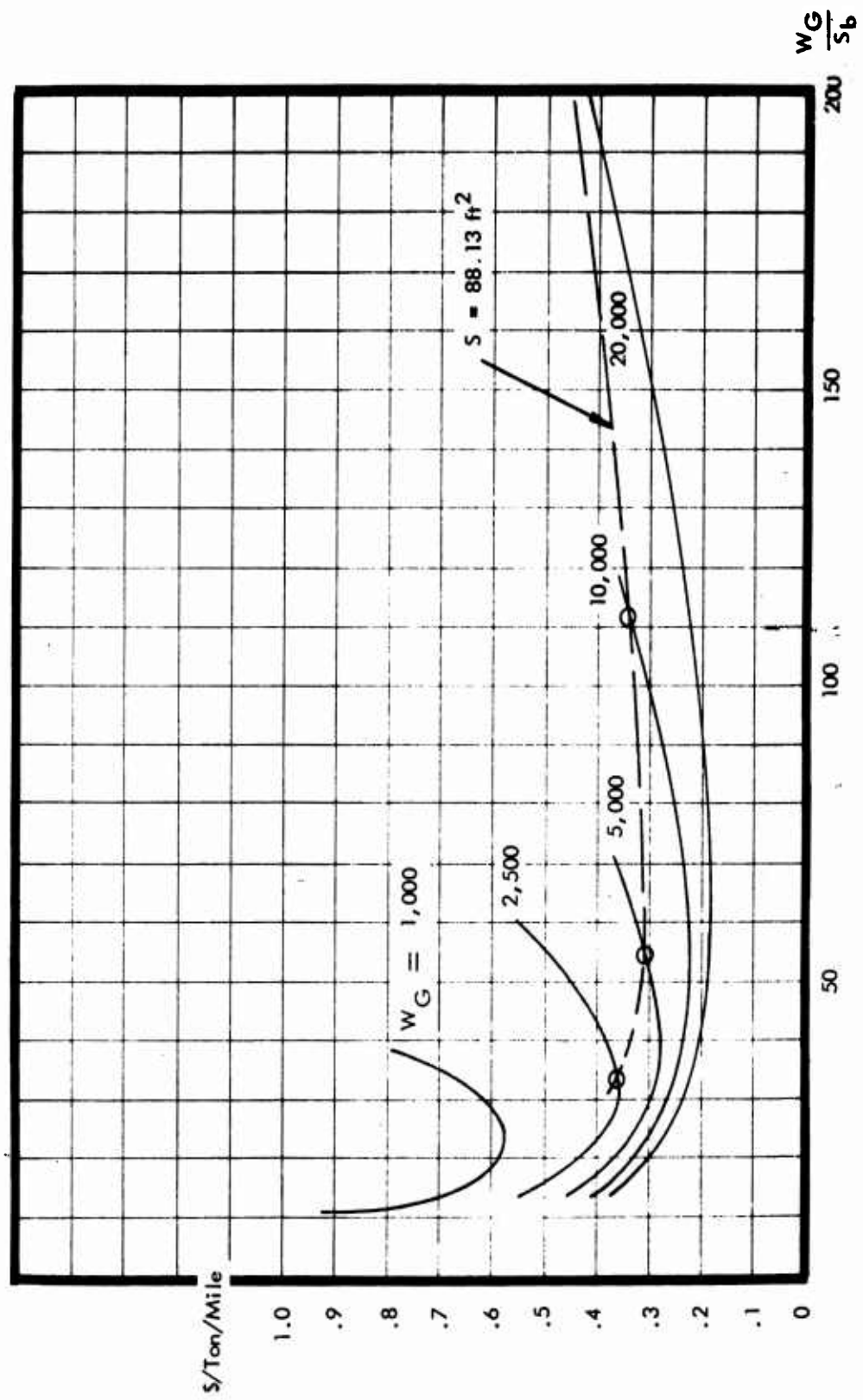


Figure 42. Cost/Ton/Mile vs. $\frac{W_G}{S_b}$ (Fuel on board)

Values of tractive force required to negotiate slopes up to 60 per cent are tabulated for a range of gross weights in Table 59.

Turning Radius

The centrifugal force applied to the center of gravity of the air cushion trailer is given by the equation:

$$F_c = \frac{W_G}{g} \cdot \frac{v^2}{r}$$

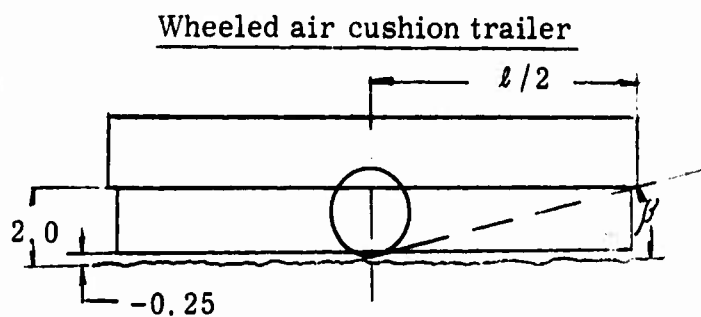
Since the maximum turning speed considered is 15 miles per hour, it is necessary to check the forces for different turning radii only for a range of speeds up to this figure. Table 60 provides the side force due to turning for six turning radii and five gross weight.

It will be obvious that in order to provide a reasonable towing condition, it will be necessary to provide ACT's with some form of ground contact.

Break Angle

To evaluate the handling characteristics of the ACT, it is important to find the road break angle.

Two vehicle configurations, a pure air cushion trailer and a wheeled air cushion trailer, are examined for different vehicle lengths ($L: w = 2:1$) and for the cases depicted in the following sketch.



$$\tan \beta = \frac{2/\frac{l}{2}}{1} = 4/l$$

TABLE 59
TRACTIVE FORCE FOR DIFFERENT SLOPES AND GROSS WEIGHT

			Ft. (lb)				
Slope		sin	W_G	W_G	W_G	W_G	W_G
			1000 lb.	2500 lb.	5000 lb.	10000 lb.	20000 lb.
5	2.86	0.050	50	125	250	500	1000
10	5.75	0.100	100	250	500	1000	2000
15	8.52	0.148	148	370	740	1480	2960
20	11.30	0.196	196	490	980	1960	3920
25	14.00	0.243	243	608	1216	2432	4864
30	16.70	0.287	287	718	1436	2872	5744
35	19.30	0.330	330	825	1650	3310	6620
40	21.80	0.372	372	930	1860	3720	7440
45	24.30	0.412	412	1030	2060	4120	8240
50	26.50	0.446	446	1115	2300	4600	9200
55	28.80	0.482	482	1205	2500	5000	10000
60	31.00	0.515	515	1288	2576	5152	10304

Note: These slope requirements do not impose any higher tractive force than that required for towing conventional trailers. It can therefore be assumed that the tractor capable of towing conventional trailers will also be able to tow an ACT of the same gross weight.

TABLE 60
SIDE FORCE DUE TO TURNING FOR DIFFERENT
SPEEDS AND GROSS WEIGHTS

		F_c (lb)					
	W_G ft	R = 100 ft	R = 250 ft	R = 500 ft	R = 750 ft	R = 1000 ft	R = 1500 ft
5	1,000	20.9	8.9	4.5	3.9	3.7	1.4
	2,500	42.9	17.8	8.9	5.9	4.3	2.8
	5,000	83.7	33.5	17.8	11.8	8.5	5.5
	10,000	168.5	67.0	33.5	22.5	17.0	11.0
	20,000	335.0	134.0	967.0	45.0	34.0	22.0
10	1,000	83.5	33.4	16.7	11.2	8.4	5.6
	2,500	167.0	66.8	33.4	22.3	16.8	11.2
	5,000	334.0	133.5	66.8	44.5	33.5	22.3
	10,000	668.0	267.0	133.5	89.0	67.0	44.5
	20,000	1,336.0	534.0	267.0	178.0	134.0	89.0
15	1,000	184.1	73.7	36.9	24.6	18.5	12.8
	2,500	368.2	147.3	73.7	49.2	36.9	24.5
	5,000	736.3	294.5	147.3	98.3	73.8	49.0
	10,000	1,472.5	589.0	294.5	196.5	147.5	98.0
	20,000	2,945.0	1,178.0	589.0	393.0	295.0	196.0

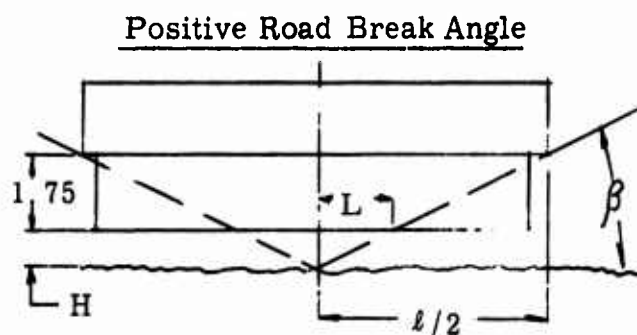
Note: The centrifugal forces applied to the center of gravity of the trailer will bring the ACT out of the path followed by the tractor. In the case that they are limited by a restricted articulated joint, the equilibrium of the tractor may be upset. Also, wind forces will produce a fishtailing motion. Some form of ground contact is therefore necessary.

A table of these values of P follows:

TABLE 61 ROAD BREAK ANGLE - WHEELED ACT	
Length ft.	Angle β
6	33.68°
8	26.57°
10	21.80°
12	18.43°
14	15.95°
14.4	15.53°

Pure Air Cushion Trailer

For this configuration, two different cases, a positive and a negative road break angle, are considered.



It is considered that when the trailer meets a break in the road, the ends of the skirt collapse and the equilibrium requirement forces the vehicle to rise in order to maintain the same escape area as in normal hovering conditions.

Therefore, considering for all the vehicle lengths, a constant $\frac{L}{w} = 2$.

$$S = (2\ell + 2w)h = 3\ell \cdot h$$

and for $L = 0.25$,

$$S = 0.75 \ell$$

Since the escape area should match the area when the skirt collapses:

$$S = 0.75 \ell = H \cdot L \times 2 = 2 H \cdot L$$

$$2 H \cdot L = 0.75 \ell$$

$$H = \frac{\ell}{2} \tan \beta - 1.75$$

$$L = \frac{H}{\tan \beta} = \frac{\ell}{2} - \frac{1.75}{\tan \beta}$$

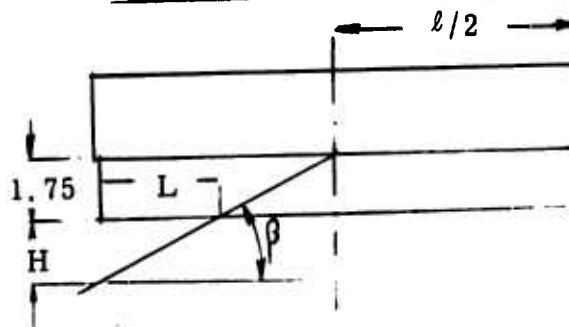
then:

$$\frac{0.75 \ell}{2} = \frac{2}{4} \tan \beta + \frac{1.75^2}{\tan \beta} - 1.75 \ell$$

For different values of ℓ , values of the break angle β are tabulated in Table 62.

TABLE 62 POSITIVE ROAD BREAK ANGLE - PURE ACT	
ℓ ft.	β degrees
6	49.0
8	39.7
10	38.8
12	29.0
14	25.5
14.4	24.7

Negative Road Break Angle



Assuming the same considerations with regard to the air escape area:

$$S = 0.75 \ell = 2 \left[\frac{\ell}{2} H + 2 H \cdot L \right]$$

$$H = \frac{\ell}{2} \tan \beta - 1.75$$

$$L = \frac{H}{\tan \beta} = \frac{\ell}{2} - \frac{1.75}{\tan \beta}$$

then

$$\frac{3}{4} \ell^2 \tan \beta + \frac{2 \times 1.75^2}{\tan \beta} - 4.75 \ell = 0$$

For different values of ℓ the break angle values are tabulated in Table 63.

TABLE 63 NEGATIVE ROAD BREAK ANGLE - PURE ACT	
ℓ ft.	β degrees
6	37.3
8	29.5
10	24.3
12	20.7
14	17.8
14.4	17.5

From Table 61, 62 and 63, it is clearly seen that the advantage of the pure ACT over the wheeled ACT in the positive road break angle is overcome by the unlimited negative break angle of the wheeled ACT. On the other hand, it can be expected that due to the spring systems in the wheels of the wheeled trailer, the same positive break angle of the pure ACT would be realized.

The break angle for the optimum size air cushion trailer is smaller than for the conventional trailer, but a compromise can be reached for

operation in a very broken terrain by keeping the maximum width and reducing the length, thus obtaining a more efficient vehicle since the planform will be nearly square. This will improve the cost/ton/mile of the lighter machines, and although the cost will still be higher than for the optimum machines; it will have greater flexibility.

7.4 DESIGN CHARACTERISTICS OF THE OPTIMUM ACT

The characteristics of the optimum ACT are:

Weights

Structural weight	1,690 lb.	
Power plant weight	617	
Empty weight		2,367 lb.
Fuel weight	488	
Payload weight	2,202	
Disposable weight load		2,690
Gross weight		<u>4,997 lb.</u>

Dimensions

Over-all length	14.40 feet
Over-all width	8.00 "
Platform width	7.20 "
Platform area	103.68 feet ²
Cushion area	88.13 "
Skirt clearance	0.25 feet
Land-structure clearance	2.00 "
Over-all height	4.50 "

Power Plant

1. 250 HP engine
2. Fan

Cost

Initial cost per vehicle (100 vehicles)	\$ 21,722.00
Cost per ton-mile (fuel in)	0.31
Cost per ton-mile (fuel out)	0.25

The general configuration of the vehicle is shown in Figure 41 .

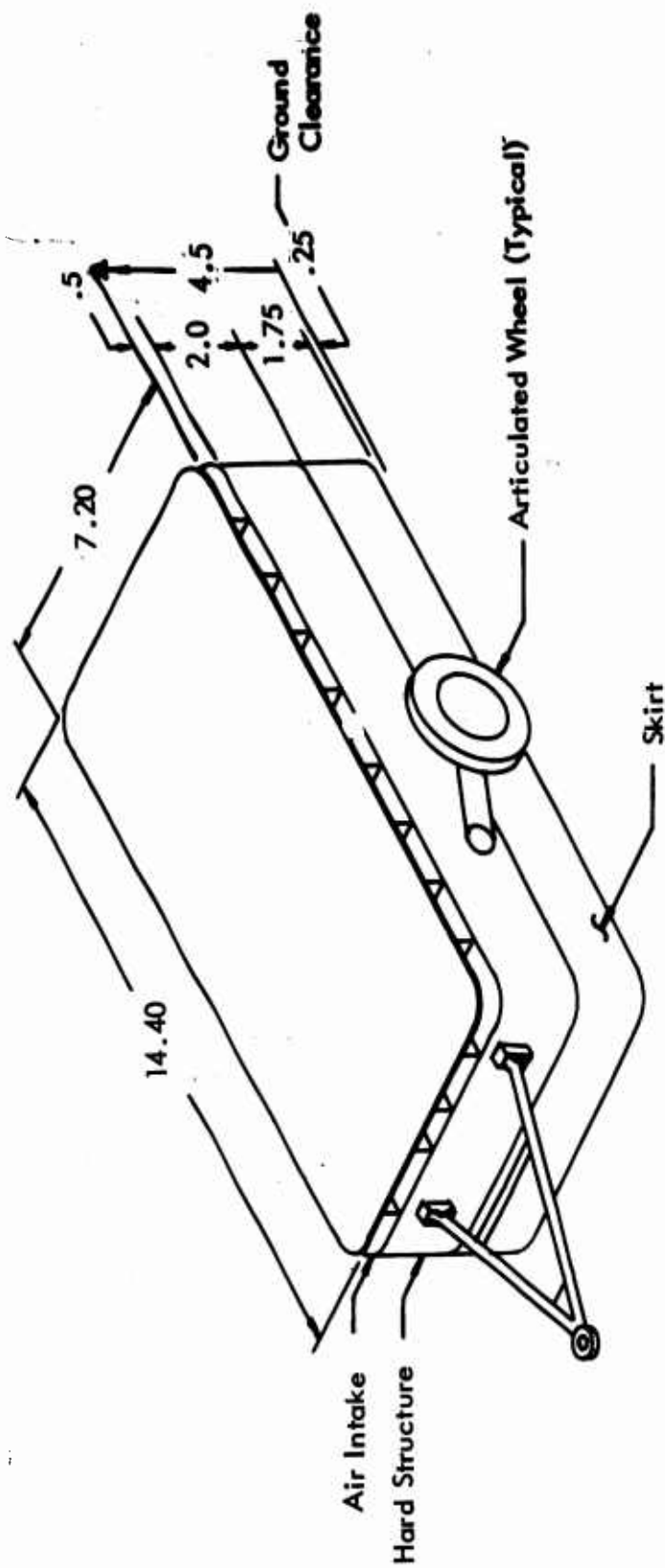


Figure 43. Air Cushion Trailer ---- General Configuration

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